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EDITOR'S COMMENTS

The first article in this issue is a review of Dissociative Identity Disorder by Nishita Paruchuri, a student at the Thomas Jefferson High School for Science and Technology. This disorder is characterized by two or more personalities with different experiences, behavior, cognition, perception, and thinking. Other names for the disorder are multiple personality disorder and split personality disorder. The purpose of the article is to improve understanding by reviewing the literature on the development, diagnosis and treatment, biological basis, and cognitive effects of this disorder.

The rest of this issue is devoted to the Communiqué of the Ontology Summit that was held during the first half of 2023. An ontology is a way of showing the properties of a subject area and how they are related, by defining a set of terms and relational expressions that represent the entities in that subject area. Ontologies and other related semantic resources have long been developed to improve communication between individuals and computing systems. However, because developing and employing ontologies can be difficult, many tools and techniques have been developed to help scientific researchers. The Ontology Summit 2023 Communiqué provides an overview of the current environment of ontological methods, tools and best practices across the ontology development life-cycle as well as some of the remaining challenges that require further research.

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Kenneth Baclawski

Journal of the Washington Academy of Sciences

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The Complexity of Dissociative Identity Disorder
A Literature Review

Nishita Paruchuri
Thomas Jefferson High School for Science and Technology

Abstract

Dissociative Identity Disorder (DID) is a neuropsychiatric disorder that affects an individual's memory retention and can hinder their daily lives. DID is widely misrepresented and misunderstood by society. Furthermore, DID is also commonly misdiagnosed by medical professionals because of its symptoms are similar to other psychiatric disorders. The purpose of this article is to help understand DID better by reviewing the DID literature on the development, diagnosis and treatment, biological basis, and cognitive effects of this disorder. Post-traumatic stress disorder (PTSD) has many of the same symptoms as DID as well as similar neurodevelopmental origins, but there are DID symptoms that do not occur in PTSD. There are several models of DID, and we discuss the Trauma Model and Socio-Cognitive Model of DID. Current research about the neurobiology and development of DID generally favors the Trauma Model. We conclude that while research about DID is advancing. more research is needed to better understand the neurodevelopmental origins of DID and to better diagnose DID.

Introduction

DISSOCIATIVE IDENTITY DISORDER (DID) is a complex psychiatric disorder, often described as a complex form of posttraumatic disorder (PTSD; Reinders et al., 2014). According to the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV), DID is characterized by two or more personalities with different experiences, behavior, cognition, perception, and thinking (American Psychiatric Association, 2013). Individuals with PTSD might experience hyperarousal, in which they experience flashbacks about their traumatic events (Lanius et al., 2010). Similarly, individuals with DID might have a hyper-aroused personality state in which they experience the 'positive' hyperaroused (Nijenhuis & van der Hart, 2011) symptoms (Reinders et al., 2014). Negative symptoms are when a person experiences hypo-arousal, is emotionally numb, and faces depersonalization and derealization (Lanius et al., 2010). These symptoms are common in the hypo-aroused state of DID and dis-

sociative PTSD (Reinders et al., 2014). The hyperarousal state undermodulates emotion regulation and can activate the flight-or-fight mode, whereas the hypo-aroused state overmodulates emotion regulation and can cause depersonalization or derealization (Reinders et al., 2014). Some individuals with DID might be more prone to one type of personality state and face either hyper-arousal or hypo-arousal, but others might alternate between the two types (van der Hart et al., 2006; Lanius et al., 2010). People with DID also experience dissociative amnesia, a common symptom. Dissociative amnesia in DID is characterized as having recurrent gaps in autobiographical memory and recollection of everyday events (Dimitrova LI et al., 2023), which could be due to the presence of multiple personalities that can engender disturbances in identity. A person with DID has a dominant personality, the host, and one or more alter personalities (Hartmann & Benum, 2019). Some people with DID can switch between their alters whenever they desire; other times people switch alters because of a trigger; and some do not have any control over switching between their personalities. The host personality might not show symptoms of mental health disorders, even though the alter personalities score very high on assessments for mental health disorder diagnosis (Hartmann & Benum, 2019). A person with DID that does not have control over switching between their identity states can face social difficulties and might develop imposter syndrome in their bodies.

The dissociative symptoms of DID can cause distress and anxiety, and people with DID also have issues with eating, personality, mood, and substance use disorders (Brand et al., 2016). Many other mental health illnesses and disorders, such as anxiety and depression, also have similar symptoms leading medical health professionals to overlook the possibility of DID inducing many people to be misdiagnosed with other disorders (Brand et al., 2016). The dissociative symptoms are linked to severe childhood trauma for people with DID (Pietkiewicz, 2021). Some people feel ashamed and uncomfortable sharing their childhood trauma with medical professionals, which can also lead to misdiagnosis (Brand et al., 2016). On the contrary, false-positive cases are common, in which people think they have DID and can get angry or disappointed when diagnosed otherwise (Pietkiewicz, 2021).

The sociocognitive model assumes that DID is regulated by high

fantasy proneness and results from sociocultural influences, simulation, or suggestive psychotherapy (Chalavi et al., 2015a; Reinders et al., 2014). Some members of society might believe this model and not get tested for the disorder or overlook the disorder as another health issue. Current, ongoing in-depth research about DID gives a neurobiological explanation of the severity of the disorder and its relation to PTSD (Reinders et al., 2014). On the contrary, the trauma-related model suggests that DID might be related to severe and chronic childhood trauma like neglect and abuse, lack of affect-regulation of caregivers, and disorganized attachment by caregivers (Boon & Draijer, 1993a; van der Hart et al., 2006). This model indicates that DID is a childhood-onset posttraumatic disorder (Chalavi et al., 2015a; Reinders et al., 2014). The trauma-related model is supported by similar volumetric reductions in gray matter and activation of similar brain structures (Chalavi et al., 2015a; Reinders et al., 2014; Reinders et al., 2018); however, more research is needed to understand DID's neurobiological and cognitive development.

The purpose of this paper is to explore and discuss neurobiological, cognitive development, and stigma around DID, and we will be addressing the following, (1) the development of DID, (2) the diagnosis and treatment, (3) the biology of DID, (4) the cognition of DID.

Development

DID commonly develops because of traumatic events during childhood, including abuse, emotional neglect, and disturbed attachment, which happen chronically (Sar et al., 2017). While PTSD commonly develops from a single traumatic event, DID is described as a chronic posttraumatic disorder (Sar et al., 2017), suggesting that people with DID most likely experience chronic trauma during childhood. Although DID is not a genetic disorder, its development might be linked to epigenetics and the inheritance of specific genes (Sar et al., 2017) that causes people to become more susceptible to the disorder. Cortical volume abnormalities in people with DID were mainly caused by surface area differences, which could be influenced by genetic and environmental factors (Chalavi et al., 2015). DID can also develop because of trauma-related neurobiological responses (Sar et al., 2017). Early life stressors could cause detrimental effects on the maturation of the brain and possibly facilitate the development of DID

(Houtepen et al., 2016; Reinders et al., 2018).

The number of alter states in a person with DID significantly correlates with the different ways that person was abused as a child (Marchwicki, 2004), suggesting that differences in alter states might depend on the severity and type of childhood abuse a person faced. Severe chronic trauma can profoundly affect a child's identity, memory, and self-organization (Wilkson & DeJong, 2020). Sometimes the abuse, such as sexual abuse, that children face is not validated by the adults in their lives, which can lead them to be confused and develop negative thoughts about themselves, which can cause them to take refuge in fantasy and could be the foundation for identity confusion (Wilkson & DeJong, 2020). This suggests that abuse and neglect can engender dissociative symptoms. Dissociation is more common in childhood than adulthood; therefore, children who face severe trauma may be more vulnerable to relentless dissociative episodes (Wilkson & DeJong, 2020); however, the dissociation can become problematic when it happens with higher frequency and intensity (Marchwicki, 2004). These findings indicate that children who dissociate more often, possibly because they face severe chronic abuse, could have a higher chance of developing DID. A study done by Hartmann & Benum (2019) tested the theory of trauma-related structural dissociation of the personality (van der Hart et al., 2006), which views dissociation as a coping mechanism due to the unbearable strains on the body and mind, ultimately resulting in the fragmentation of the developing personality. The fragmentation splits painful emotions and trauma, therefore functioning to meet the needs to continue daily life, suggesting that children can use dissociation as a defense mechanism to separate feelings, thoughts, and memories giving rise to the maturation of an alter personality. Even though dissociation could be used as a defense and coping strategy to continue daily living, it could cause detrimental effects on both the host and alter personalities (e.g., cognitive deficits, loneliness, lack of commitment, and emotion regulation; Harmann & Benum, 2019).

The characteristics of the alter personalities can vary in gender, age, race, and culture and be different from the host personality (Marchwicki, 2004). Each personality also has independent perceptions and thinking about the self and the environment (Hartmann & Benum, 2019), suggesting that alter personalities can have thoughts and feelings of their own

which could arise from unique characteristics (e.g., gender, age, race, and culture) that enable them to act independently from each other. Personalities can also differ in behavioral differences; some might have different menstrual cycle times and handwriting (Pobacha, 2000). Sometimes the personalities, both the host and alters, might know about the existence of the other personalities. The host is usually the most stable; however, in some situations, the alter personality might have better coping skills, which helps the host personality when needed (Cudzik et al., 2019). The switches between personalities might not be very noticeable. However, there could be sudden changes in behavior, the way the person talks, heart rate, breathing, and facial expression, and there might even be changes in the person's voice (Cudzik et al., 2019). The switches can happen because of triggers, which can be anything that cues the awakening of another personality, or an individual could have complete control over how they switch between personalities. Sometimes an individual might not have any control over the switches between personalities.

Most people are diagnosed with DID as adults, even though the disorder might have been developing from childhood because the symptoms might be confused with problems with learning and behavior. The varying psychopathological symptoms that people might face have a loss of memory, amnesia in different periods of life, feeling that there is an existence of another person inside, forgetting parts of their childhood, and failure to recognize individuals that they are close with (Cudzik et al., 2019); however, these symptoms might be different in each person, which is why physicians need to have an understanding of DID before trying to diagnose patients. Physicians need to help DID patients understand and know about their different personality states. It is also essential to recognize that the unique characteristics of the personalities might not be the same from person to person and could cause differences in the behavior of individuals with DID. DID could be challenging to recognize because of people's varying symptoms and behaviors; however, raising awareness about the disorder and understanding its origins could help society change its conflicting viewpoints on what DID is and how it develops.

Diagnosis and Treatment

Currently, there are many methods of diagnosis and treatment for

DID; however, the negative stigma around DID and controversies surrounding the methods of diagnosis and treatment make it difficult to accurately diagnose and treat DID. The current guidelines regarding DID diagnosis in the tenth edition of the International Classification of Diseases (ICD-10) and the DSM-IV are inaccurate in differentiating between legitimate and false-positive DID cases (Pietkiewicz, 2021). The guidelines in ICD-10 also describe DID as rare, a common misconception in society (Pietkiewicz, 2021). Not only did the ICD-10 describe DID as rare, but many psychology textbooks declare the same notion. However, Brand et al. (2016) found that 1.1-1.5% of people in representative community samples have DID. Likewise, Sar et al. (2014) observed the percentage of adolescent psychiatric outpatients with DID and discovered that 16.4% had DID, with 45.2% having a dissociative disorder. These numbers support the idea that DID is not rare and contradict statements made by the guidelines most medical professionals use to diagnose DID.

One of the most common misconceptions about DID is that the disorder is overdiagnosed (Brand et al., 2016). On the contrary, DID is often misdiagnosed as other disorders, including borderline personality disorder, PTSD (14.3%), schizophrenia (9.9%), and major depression (6.6%) because DID shares common symptoms with these disorders (Brand & Lanius, 2014; Brand et al., 2016). Some clinical professionals' skepticism against DID could lead them to develop bias, which is evident in the diagnosis process. Perniciaro (2014) observed that 60.4% of U.S. clinicians could correctly determine whether a person had DID based on the descriptions of symptoms that person experienced. One of the most common reasons for DID misdiagnosis is medical professionals overlooking the possibility of dissociative disorder and its symptoms. Educating clinicians about dissociative disorders like DID can increase the accurate diagnosis of the disorder. Dorahy et al. (2005) found a connection between clinicians misdiagnosing DID and their lack of training and knowledge about DID. A study in Australia found similar connections between a lack of knowledge about DID and DID misdiagnosis (Leonard et al., 2005). They further concluded that people with DID embarrassed to share their experiences and symptoms have even more trouble talking about their disorder to clinicians who show bias against DID. DID is not an overdiagnosed disorder and is often misdiagnosed due to medical professionals' skepticism and symptoms that lead to a diagnosis

of other disorders.

To help with diagnosis, many clinicians use DID evaluation tools. The Dissociative Experiences Scale (DES) is a self-reported assessment that tests the absorption of outside information and dissociative symptom severity (i.e., depersonalization, derealization, and amnesia; Dubester & Braun, 1995). The Dissociation Questionnaire measures symptoms like identity confusion, fragmentation, loss of control, amnesia, and absorption (Mitra & Jai, 2023). The Difficulties in Emotion Regulation Scale (DERS) measure impulsivity, emotional responses under certain situations, and emotional self-regulation abilities (Hallion et al., 2018). Clinicians decide the best treatment plan for patients with DID based on their scores on these evaluation tools. Furthermore, researchers are trying to determine biomarkers for DID(Dimitrova LI et al., 2023; Reinders et al., 2019). Using biomarkers for DID screening could make diagnosis more accessible and accurate than just using the evaluation tools.

The International Society for the Study of Trauma and Dissociation Treatment Guidelines for Dissociative Identity Disorder in Adults recommends a DID treatment plan in three steps surrounding trauma-focused psychotherapy (International Society for the Study of Trauma and Dissociation, 2011). The first step is attempting to stabilize and reduce symptoms. A failure to do this can cause a deterioration in functioning and a decrease in the notion of safety (Brand et al., 2016). The second step is helping the patients to work out their trauma and regulate their symptoms. The third step is to bring the patients back into society through rehabilitation; for example, creating a support group. Some clinicians and critics believe this treatment process, involving psychotherapy, increases dissociative symptoms, which are harmful to patients; however, these claims lack substantial evidence (Brand et al., 2016). A study done by Brand et al. (2013) reported data collected from DID patients and their clinicians about the effectiveness of the DID treatment process. Over 30 months, they observed that patients showed a decrease in hospitalization, self-harm, drug use, symptoms such as dissociation and depression, and a decrease in PTSD symptoms. They found that clinicians reported increased social activity and academic skills among DID patients. The three-stage treatment process for DID does help patients decrease their symptoms and return to society.

Other therapy options for DID include cognitive behavioral therapy (CBT), dialectical behavioral therapy (DBT), eye movement desensitization and reprocessing (EMDR), psychodynamic therapy, schema therapy, and hypnotherapy. CBT focuses on treating negative thoughts, depression, and anxiety (Pruthi, 2018). Research shows that individuals with dissociative symptoms could benefit from cognitive behavioral treatments (Hoeboer et al., 2020). A recent case study showed that CBT decreased PTSD and dissociative symptoms in an individual with DID, suggesting that CBT could be a therapy option (van Minnen & Tibben, 2021). DBT treats emotion dysregulation, self-harm, and suicide risk (Linehan et al., 2006; Miller, 2015; Stoffers et al., 2012). DBT is often used to treat borderline personality disorder (BPD), and individuals with BPD often have comorbid DID. Since there is comorbidity between DID and BPD and they present similar problems, DBT might help treat patients with DID (Foote & van Orden, 2016). EMDR is recommended for stable patients with coping skills and is recommended to be used as part of an integrative treatment (Mitra & Jai, 2023). The EMDR treatment process tries to work with alternate identities to intervene and reduce symptoms (Fine & Berkowitz, 2001). Psychodynamic and schema therapies treat early childhood trauma and experiences (Huntjens et al., 2019; Gentile et al., 2013). Schema therapy, specifically, involves components of CBT and focuses on reconstructing childhood trauma and cognition (Huntjens et al., 2019). Hypnotherapy has shown efficiency in treating individuals with DID (Ross, 2000). Since individuals with DID are more hypnotizable than others (Frischholz et al., 1992), hypnotherapy can assess alternate identities to enable the appearance of these identities as an intervention technique (Kluft, 1999). However, more research on hypnosis as a treatment method for DID still needs to be researched. All these treatment methods are possible interventions to help reduce the symptoms of DID; however, most of these techniques are still under discussion and need more research to reduce DID symptoms efficiently.

There are no specific medications for DID (Mitra & Jai, 2023). Medications are not the primary treatment for DID (Mitra & Jai, 2023); however, the most common medications given to individuals with DID are for mood disorders and PTSD (Loewenstein, 1991). The different identity states in individuals with DID could portray different symptoms, making

it harder to prescribe a specific medication (Mitra & Jai, 2023). Literature shows that medication has not effectively treated DID (Dorahy et al., 2014).

There has been growth in attempts to find biomarkers for DID to make diagnosis more accessible and use treatment methods shown to help reduce dissociative symptoms. However, more research is needed to develop efficient treatment and diagnosis plans for individuals with DID.

The Biology

The Frontal Lobe

The frontal lobe contains structures involved in controlling executive functioning, emotion regulation, critical thinking, and motor skills (Blihar et al., 2020). Individuals with DID have reduced volume in the global frontal lobe and/or subfields of the frontal lobe (Chalavi et al., 2015a; Reinders et al., 2018; Reinders et al., 2019). Deficits in the cortical volume and surface area in the frontal lobe were correlated with dissociative symptoms in individuals with DID (Reinders et al., 2018). These findings suggest that atrophy in the frontal lobe plays a vital role in the development of DID. Some structures of the frontal lobe that are involved in the development of DID include the prefrontal cortex, which includes the orbitofrontal cortex, and the cingulate cortex (Chalavi et al., 2015a; Reinders et al., 2014; Reinders et al., 2018; Reinders et al., 2019; Sar et al., 2007).

The prefrontal cortex is involved in emotion regulation and working memory (Reinders et al., 2014; Vissia et al., 2022). Individuals with the dissociative subtype of PTSD show hyper-activation in the prefrontal cortex and anterior cingulate cortex, which inhibit subcortical areas like the amygdala and insula that are involved with fear and perception, which is known as emotional overmodulation (Felmingham et al.,2008; Lanius et al., 2010). Individuals with DID who are in the hype-aroused state show similar activation patterns in cortical brain areas as people with the dissociative subtype of PTSD, which inhibit the arousal of the sympathetic nervous system (Reinders et al., 2014), which supports the trauma model of DID. Research suggests that cortical brain areas like the prefrontal cortex are involved in overmodulating the hypo-aroused state in DID (Lianus et al., 2010; Reinders et al., 2014; Vissia et al., 2022). In DID, emotion regu-

lation depends on working memory (Okon-Singer et al., 2015). Activation in the ventrolateral prefrontal cortex was shown in individuals with the hypo-aroused state, but not the hyper-aroused state, of DID (Vissia et al., 2022). The hyper-aroused state of DID is associated with lower working memory due to lower activation of the prefrontal cortex, which causes it to under-modulate emotions (Vissia et al., 2022). Individuals with DID have prefrontal cortex atrophy (Chalavi et al., 2015a; Reinders et al., 2018). Furthermore, atrophy in the prefrontal cortex's surface area and cortical volume is associated with dissociative symptoms (Reinders et al., 2014; Reinders et al., 2018; Reinders et al., 2019). A systematic review gathered that dissociative amnesia, a common dissociative symptom in DID, is associated with prefrontal, temporal, and limbic dysfunction (Taïb et al., 2023). This supports the association between dissociative symptoms and the prefrontal cortex. Reinders et al. (2019) suggested that the prefrontal cortex can be used as a neuro biomarker since its atrophy is associated with dissociative symptoms and possibly because it plays a vital role in emotion regulation in individuals with DID (Reinders et al., 2014).

The orbitofrontal cortex plays a role in the development of symptoms in DID. The surface area reduction of the orbitofrontal cortex is associated with dissociative symptoms (Reinders et al., 2018), which supports the orbitofrontal model of DID. The orbitofrontal model of DID states that the development of the orbitofrontal cortex in an early abusive environment supports the involvement of the orbitofrontal cortex in DID. The orbitofrontal cortex plays a vital role in the activation and inhibition of the limbic system (Schore, 2012), and an orbitofrontal cortex that matures in an abusive environment could affect emotion regulation in the limbic system (Lanius et al., 2012; Reinders et al., 2014). Sar et al. (2007) proposed that increased perfusion, blood flow, and rates in the medial and superior frontal and occipital lobes could cause hypo-perfusion in the orbitofrontal cortex. Hypo-perfusion of the orbitofrontal cortex might be associated with impulsivity, including anger, that could cause self-destructive behavior, a common symptom in individuals with DID (Sar et al., 2007). This indicates that abnormalities in the orbitofrontal cortex could be associated with the development of common symptoms in individuals with DID. The involvement of the orbitofrontal cortex in DID can be used in developing treatment methods for DID (Reinders et al., 2018).

The cingulate cortex is involved in emotion regulation, fear processing, and memory processing. These factors are often impaired in individuals with DID (Blihar et al., 2020) and therefore support involvement of the cingulate cortex in DID. Individuals with DID showed gray matter volumetric reductions (Reinders et al., 2018; Reinders et al., 2019), which were associated with dissociative symptoms (Reinders et al., 2019), suggesting that the anterior cingulate might be involved in the development of dissociative symptoms in DID. The spatially distributed reductions in the anterior cingulate cortex are similar in DID and PTSD, which supports the trauma model of DID. The hypo-aroused state of DID activates the cingulate gyri, which suggests the involvement of the cingulate cortex in emotion regulation in individuals with DID. More in-depth and extensive research should be done to discover possible associations between the cingulate cortex and emotion regulation and the development of symptoms in DID.

The Temporal Lobe

The temporal lobe is involved in processing visual and auditory perception (Siegel & Sapru, 2015). Temporal lobe atrophy is associated with dissociative symptoms in DID (Reinders et al., 2018; Reinders et al., 2019), and decreased temporal lobe activity is associated with the development of dissociative amnesia (Taïb et al., 2023). It can be speculated that abnormalities in the temporal lobe are involved in the development of dissociative symptoms in DID, including dissociative amnesia, which causes people to have deficits in their autobiographical memory. The parahippocampal gyri, located in the medial temporal lobe, plays a pivotal role in the suppression of unwanted autobiographical memories in the hypo-aroused state of DID (Reinders et al., 2014), suggesting that the temporal lobe could also be involved in memory regulation in the hypo-aroused state in DID. The occipital lobe is involved in visual perception. The occipital lobe is associated with dissociative symptoms in DID (Reinders et al., 2018) and is indirectly involved in impulsive symptoms, common in DID (Sar et al., 2007). These findings indicate that the occipital lobe is most likely involved in the development of common core symptoms in DID. The posterior-multimodal areas, including temporal and occipital regions, are involved in memory access in the hyper-aroused state of DID by regulating the presence of identity states and suppressing unwanted autobiographical memory (Reinders et al., 2014), indicating that the occipitotemporal region

plays a role in memory regulation in individuals with DID. Atrophy in the occipitotemporal junction is associated with dissociative symptoms in DID (Reinders et al., 2018; Reinders et al., 2019). People with DID may have difficulties tolerating ambiguity, so they have trouble recognizing emotions from neutral facial expressions (Grillon et al., 2008; Holaway et al., 2006; Schlumpf et al., 2013). A possible reason could be because of deficits in the occipitotemporal region, which is face sensitive (Schlumpf et al., 2013), and atrophy in this region might cause difficulties in perception in people with DID. More research on the occipital and temporal lobes is needed to identify their role in the perception and development of dissociative symptoms in individuals with DID.

The Parietal Lobe

The parietal lobe is involved in processing somatosensory perception (Blihar et al., 2020) (e.g., thermoception, nociception, equilibrioception, mechanoreception). Reduced matter in the inferior parietal cortex regions is associated with dissociative symptoms in individuals with DID (Chalavi et al., 2015; Reinders et al., 2018; Reinders et al., 2019), suggesting that a smaller inferior parietal cortex could be involved in individuals with the development of issues with self-expression, interpretation, and derealization in individuals with DID (Blihar et al., 2020). In DID, individuals in the hyper-aroused state do not activate the parietal cortex during linear load (Vissia et al., 2022). Furthermore, the hypo-aroused state of DID activated the parietal cortex more than the hyper-aroused state (Vissia et al., 2022). These findings suggest that individuals in the hyper-aroused state of DID might have lower somatosensory perception as task difficulty increases. More research is needed on the parietal lobe and its function in DID symptomatology.

The Limbic System

The Limbic System contains a set of structures that support emotion and memory processing and take part in controlling behavior, endocrine and autonomic functioning (Blihar et al., 2020). Changes in structures in this lobe, like the hippocampus, insula, dorsal striatum, and amygdala, have been associated with the development and symptoms of DID (Chalavi et al., 2015a; Chalavi et al., 2015b; Dimitrova LI et al., 2023; Ehling et al., 2007; Reinders et al., 2014; Reinders et al., 2019; Vermetten et al., 2006).

The hippocampus is involved in processing short-term memory and long term-memory for up to 1 year, and it also takes part in spatial and contextual learning and inhibition of emotional responses (Ehling et al., 2007). Research has shown hippocampal atrophy in people with DID with comorbid PTSD (Chalavi et al., 2015a; Chalavi et al., 2015b; Vermetten et al., 2006); however, some research has proposed that hippocampal atrophy in individuals with DID might be due to severe PTSD that develops from childhood traumatization (Chalavi et al., 2015a; Wigner et al., 2008). On the contrary, significant negative correlations between dissociative symptoms and the volumes of the left subiculum, which is involved in memory retrieval, and presubiculum subfields of the hippocampus have been found (Chalavi et al., 2015b), suggesting that hippocampal abnormalities could cause the dissociative symptoms which only pertain to dissociative disorders, and not other disorders. The hippocampus could also be involved in memory regulation in the hypo-aroused state in DID (Reinders et al., 2014). There is a negative association between the degree of childhood traumatization and hippocampal atrophy in individuals with DID (Chalavi et al., 2015a; Chalavi et al., 2015b; Reinders et al., 2019), suggesting that more intense and prolonged childhood trauma could cause higher levels of atrophy in hippocampal volume (Blihar et al., 2020). The stress hormone glucocorticoid could cause this phenomenon (Chalavi et al., 2015b; Vermetten et al., 2006). Glucocorticoids are released during stressful experiences (Chalavi et al., 2015b; Vermetten et al., 2006), and extensive glucocorticoid exposure can cause hippocampal atrophy (Vermetten et al., 2006). Hippocampal subfields CA2-3 and subiculum have the highest number of glucocorticoid receptors, so they are most likely to be affected by chronic stress (Chalavi et al., 2015b). Atrophy of other hippocampal subfields like CA2-3 and CA4-DG is also associated with childhood traumatization (Chalavi et al., 2015b). The interconnection between childhood traumatization and dissociative symptoms might cause hippocampal atrophy in individuals with DID (Chalavi et al., 2015b; Dimitrova LI et al., 2023). The CA1, a subfield of the hippocampus, is associated with dissociative amnesia, a common dissociative symptom in DID, and emotional neglect, a type of childhood trauma. (Dimitrova LI et al., 2023). Dimitrova LI et al. (2023) found that this association was still significant after they controlled for comorbidity, suggesting that CA1 atrophy is a phenomenon that could be specific to dissociative disorders as it is predominantly caused by dissociative amne-

sia in people with DID. CA1 is involved in encoding and the retrieval of contextual memory Daumas et al. (2005), was found to be essential for autobiographical memory (Bartsch et al., 2011), and might cause memory disturbances (Dimitrova LI et al., 2023). These findings suggest that CA1 damage could be a reason for recurrent gaps in autobiographical memory and memory retrieval in people with DID, which is why Dimitrova LI et al. (2023) suggest that CA1 atrophy can be used as a biomarker for DID. Since the CA1 projects into the medial prefrontal cortex and orbitofrontal cortex (Zhong et al., 2006), the CA1 may be involved in the development of dissociative personality states and dissociation mechanisms (Forrest, 2001). These findings suggest that the hippocampus has a part in the development of symptoms of DID.

The dorsal striatum and insula are also associated with the development of DID (Chalavi et al., 2015a; Reinders et al., 2014). The dorsal striatum comprises the caudate nucleus, putamen, and palladium (Chalavi et al., 2015a) and is involved in decision-making (Balleine et al., 2007). A significant positive correlation exists between bilateral putamen and right pallidum volumes and the severity of depersonalization and derealization measures (Chalavi et al., 2015a). Individuals with PTSD had significantly different putamen and pallidum volumes compared with individuals with DID and comorbid PTSD, with the latter having larger striatal volumes than healthy controls (Chalavi et al., 2015a). These findings suggest that larger volumes of the dorsal striatum might be associated with dissociative symptoms in DID, and these changes are specific to dissociative disorders. Since the hippocampus is sensitive to prolonged stress, impairment in its functioning leads to higher activation of the dorsal striatum (Schwabe et al., 2008), so Reinders et al. (2014) hypothesized that stress could be associated with a shift from hippocampus involvement to dorsal striatum, especially the caudate nucleus, involvement which means that the dorsal striatum may play a vital role in modulating neutral and trauma-related identity states in DID. Reinders et al. (2016) extended these results by proposing that the caudate nucleus has a vital role in the state stability of dissociative personality states and is also involved in the retrieval of trauma-related memory instead of the hippocampus, suggesting that memory retrieval and regulation might not only pertain to the hippocampus in individuals with DID, which could be because of the prolonged stress they

faced. The insula is involved in memory and emotion processing (Siget & Sarpu, 2015). The insula was shown to be active during dissociative personality state-dependent brain functioning during emotion regulation, which overlapped with its gray matter atrophy (Reinders et al., 2014; Reinders et al., 2016), suggesting that the insula might play a vital role in the regulation of personality states in DID. The cortical volume of the insula is smaller in individuals with DID and had comorbid PTSD than in healthy controls; however, it was not significantly different from people with only PTSD (Chalavi et al., 2015a). A possible reason for this occurrence is the involvement of insular cortices with dissociative reactions in both PTSD and DID (Lanius et al., 2010; Reinders et al., 2014); however, more in-depth research on the insula and how it is associated with dissociative reactions is needed.

The amygdala is involved in processing and reacting to emotional stimuli (Ehling et al., 2007). While some studies state lower amygdala volumes in people with DID (Ehling et al., 2007; Vermetten et al., 2006), others state preserved or higher amygdala volumes in individuals with DID (Chalavi et al., 2015a; Reinders et al., 2022; Weniger et al., 2008). A possible explanation for preserved or higher amygdala volumes in individuals with DID is amygdala atrophy in these individuals might be due to the presence of PTSD (Winger et al., 2008) or that the amygdala might be less affected by stress hormones like the hippocampus (Reniders et al., 2022). On the contrary, research has shown that decreased amygdala volume might be associated with depersonalization (Irle et al., 2007), and the development of dissociative amnesia is associated with decreased activity of the amygdala (Taïb et al., 2023). These findings suggest that the amygdala could play a role in the development of dissociative symptoms in DID. Even though the literature is mixed on amygdala atrophy effects in DID, preserved or higher amygdala volumes do not rule out the possibility of amygdala deficits (Chalavi et al., 2015a). The hyper-aroused state of DID activates the insula and amygdala complexes, structures that are involved in fear and perception, activating the flight-or-fight mode (Reinders et al., 2014), indicating the involvement of the amygdala in the regulation of symptoms in the hyper-aroused state of DID. More in-depth and extensive research should be done to discover possible associations between amygdala atrophy and dysfunction and the development of DID.

The limbic system plays a vital role in memory and emotion processing (Blihar et al., 2020), and deficits in structures like the hippocampus, dorsal striatum, insula, and possibly amygdala could cause memory processing and retrieval impairments in individuals with DID (Chalavi et al., 2015a; Chalavi et al., 2015b; Dimitrova LI et al., 2023; Ehling et al., 2007; Reinders et al., 2014; Reinders et al., 2019; Vermetten et al., 2006). Even though research about the limbic system's involvement in the development of DID has grown over the years, more research is needed to understand the origins of the dissociative and depersonalization symptoms present in DID.

Biology Conclusion

The neurobiology of DID supports the trauma model, the proposition that DID is a complex form of PTSD (Chalavi et al., 2015a; Reinders et al., 2014; Reinders et al., 2018); however, the origin of DID symptomologies is uncertain as many structures play a role in the development of DID. Nevertheless, current research is attempting to find biomarkers (Dimitrova LI et al., 2023; Reinders et al., 2019) that can increase the accuracy of DID diagnosis and help develop treatments concentrated on the origins of DID symptomatology.

The Cognition

Cognitive inhibition is a vital process in dissociative identity disorder (DID) that appears in a state-like manner (Dorahy et al., 2006). Cognitive inhibition is the ability to withhold stimuli unrelated to the mind's current task. Cognitive inhibition is essential in selective attention, which is the ability to focus on one stream for processing while ignoring others (Neil et al., 1995). On the contrary, divided attention is when the mind can simultaneously focus on multiple information streams. Individuals with DID showed increased cognitive inhibition in a neutral context, but in the negative context, they showed decreased cognitive inhibition (Dorahy et al., 2006). This suggests that cognitive inhibition can vary with the stimulus type. This indication is consistent with the findings that effective inhibition may represent the dominance of the hypo-aroused state of DID and that weakened inhibition may represent the dominance of the hyper-aroused state of DID (Nijenhuis et al., 2002). Individuals in the hypo-aroused state

tend to be detached from their traumatic memories, and individuals in the hyper-aroused state have flashbacks to their traumatic experiences (Lanius et al., 2010). It can be speculated that cognitive inhibition could be a defensive method, as it might represent the dominance of the hypo-aroused state to detach from the traumatic memories. The decreased cognitive inhibition, which might represent the dominance of the hyper-aroused state, could be an adaptive method under threatening conditions (Dorahy et al., 2006). In potentially threatening circumstances, reduced inhibition in DID leads to higher cognitive demands, leading to a more effective divided attention processing (Dorahy et al., 2006). A more efficient divided attention process can quickly identify and detach from potentially threatening stimuli (Dorahy et al., 2006). Cognitive inhibition is involved in regulating the flow of information in working memory (Bjorklund & Harnishfeger, 1995).

Working memory functioning might vary with stimulus type and dissociative identity states (Dorahy et al., 2004). Working memory is the limited capacity system that regulates information necessary to complete tasks (Baddely, 1996). The hypo-aroused state had higher working memory functioning than the hyper-aroused state of DID (Vissia et al., 2022). According to the inefficient inhibition hypothesis (Bjorklund & Harnishfeger, 1990; Wilson & Kipp, 1998), individuals with efficient inhibition have higher working memory because they can keep irrelevant information out of their working memory. This is consistent with the cognitive inhibition differences between the two identity states. The hypo-aroused state of DID might be associated with higher working memory because its dominance is related to effective inhibition. In contrast, the opposite is true for the hyper-aroused state of DID. The hypo-aroused state displays more mental efficiency and integrative capacity, which explains why they might seem healthy (Nijenhuis et al., 2015; Vissia et al., 2022). The idea that the hyper-aroused state is associated with lower working memory is based on the indication that emotion regulation depends on working memory (Okon-Singer et al., 2015).

Individuals with DID have higher working memory than individuals with only PTSD (Weniger et al., 2008). PTSD is also characterized by working memory deficits (Weniger et al., 2008), and working memory is sensitive to acute and chronic stress (Arnsten, 1998). However, individuals with DID are characterized by having higher working memory (Weniger

et al., 2008). A possible reason for this phenomenon could be that dissociative abilities produce higher divided attention performance, indicating that individuals who dissociate more often could process multiple streams of information simultaneously (Dorahy et al., 2006). However, it is essential to note that dissociation may be related to executive deficits when tested under selective attention conditions (Freyd & DePrince, 2001). Selective attention can be characterized by differential processing (Johnson & Dark, 1986), which involves activating related information and inhibiting irrelevant information (Tipper et al., 1989). The selective attention processing style ignores the stimuli so that cognitive resources can be used for relevant information (Dorahy et al., 2006). This allows the mind to attend to one stream of information. Reduced inhibition can allow more information streams to go through processing (Dorahy et al., 2006). Low-dissociators might struggle to process information under the conditions of divided attention (Dorahy et al., 2004). This indicates that dissociation could lead to more disruptions in information processing during selective attention. However, dissociative abilities might mitigate the disruptive consequences as the pressure increases on working memory (Dorahy et al., 2004). Weakened inhibition, along with the increase in processing, plays a role in producing higher divided attention performance, decreasing the deleterious effects of higher cognitive load (Dorahy et al., 2006). It can be speculated that individuals with DID have this ability (Dorahy et al., 2006). This could explain why they have higher working memory than individuals with PTSD (Weniger et al., 2008), even though DID could develop under stressful conditions (Chalavi et al., 2015b). Aligned with these findings, individuals with DID can perform better with increasing task load than healthy controls (Elzinga et al., 2007).

Negative posttraumatic cognition predicts depersonalization and other distorted body perceptions in individuals with DID (Merker et al., 2021). Depersonalization is detachment from oneself and surroundings (American Psychology Association, 2013). Negative posttraumatic cognition is negative perceptions about the self and surroundings that started or worsened after trauma (Merker et al., 2021). Some of the negative perceptions can include the incapability to recall traumatic memories and blaming the self or others for trauma. Individuals with DID often experience depersonalization and feel that their body does not belong to them

(i.e., detachment; Merker et al., 2021). These individuals often feel that their traumatic experiences belong to someone else as a method to detach from their trauma (Frewen & Lanius, 2015). They also might place blame on their bodies to control their traumatic experiences rather than blaming their perpetrator (Steele et al., 2016). This can cause distorted body perceptions in individuals with DID (Merker et al., 2021). The negative posttraumatic cognitions might cause distorted body perceptions, including dissociation, in individuals with DID (Merker et al., 2021), suggesting that negative perceptions about the self and the surroundings can cause dissociative symptoms like depersonalization.

Although cognitive inhibition and negative posttraumatic cognition have been shown to affect information processing and working memory in individuals with DID, cognitive functioning in individuals with DID still needs to be thoroughly researched. Further research is needed on how cognitive deficits affect dissociative symptoms (e.g., dissociative amnesia, depersonalization, and derealization) in individuals with DID and their perception of the self and surroundings.

Conclusion

This empirical review on DID discusses the symptomology, treatment, diagnosis, biology, and cognition of DID. Furthermore, it presents holistic evidence from past literature that supports the notion of DID being a severe form of PTSD (Reinders et al., 2014). DID is characterized by two or more personalities that have different experiences, behavior, cognition, perception, and thinking (American Psychiatric Association, 2013). DID diagnosis depends on evaluation tools, including the DES, Dissociation Questionnaire, and the DERS (Dubester & Braun, 1995; Hallion et al., 2018; Mitra & Jai, 2023). However, these tests can sometimes be inaccurate, so diagnosis methods with higher accuracy need to be implemented. Recent research has found possible biomarkers for DID, including CA1 (Dimitrova LI et al., 2023; Reinders et al., 2019). Biomarkers will make the DID diagnosis process easier and more efficient. The treatment for DID follows three steps to reduce symptoms and let individuals enter society again (International Society for the Study of Trauma and Dissociation, 2011). Many behavioral therapy methods for DID are being researched for accuracy and efficiency (e.g., CBT, DBT, EMDR, psychodynamic therapy,

schema therapy, and hypnotherapy; Hoeboer et al., 2020; Huntjens et al., 2019; Gentile et al., 2013; Fine & Berkowitz, 2001; Foote & van Orden, 2016; van Minnen & Tibben, 2021; Pruthi, 2018; Ross, 2000). Literature shows that medication, on the other hand, is not an efficient treatment for individuals with DID (Dorahy et al., 2014). DID is often misdiagnosed, and diagnosis can also be biased due to misunderstandings about the disorder (Brand & Lanius, 2014; Perniciaro, 2014).

Research about the biology and cognition of DID can help clinicians understand the development of DID and help researchers to develop newer diagnosis and treatment methods. The brain atrophy caused by childhood trauma is associated with dissociative symptoms (Chalavi et al., 2015a; Chalavi et al., 2015b; Dimitrova LI et al., 2023; Reinders et al., 2018; Reinders et al., 2019; Taïb et al., 2023). This suggests that DID develops from severe childhood trauma (Sar et al., 2017). Although some atrophy in DID has been linked with comorbid PTSD (Chalavi et al., 2015; Weniger et al., 2008), there have been specific brain changes associated with symptoms primarily associated with DID (Dimitrova LI et al., 2023; Reinders et al., 2018; Taïb et al., 2023). This gives support to the trauma model of DID.

Cognition appears in a state-like manner in individuals with DID (Dorahy et al., 2006). Effective cognitive inhibition may represent the dominance of the hypo-aroused state of DID, and weakened inhibition may represent the dominance of the hyper-aroused state of DID (Nijenhuis et al., 2002). This also affects working memory which might vary with stimulus type and dissociative identity states (Dorahy et al., 2004). Aligned with previous findings, working memory is higher in the hypo-aroused state than in the hyper-aroused state of DID (Vissia et al., 2022). Cognition in individuals with DID is preserved because of weakened cognitive inhibition (Dorahy et al., 2006). Negative posttraumatic cognition predicts depersonalization symptoms in individuals with DID (Merker et al., 2021). This suggests that childhood trauma could cause changes in how a person perceives themselves and their surroundings.

All these findings suggest that research in DID is advancing and is providing new insights into the biology and cognition of DID. These advancements can help researchers develop more efficient diagnosis and treatment plans for individuals with DID. Findings about the neurobiology

and development of DID support the Trauma Model as well. Although research is advancing in DID, more research is needed to find faster and more accurate diagnosis methods to help treat DID. Furthermore, more research is needed in order to understand the neurodevelopmental origins of DID.

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References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders: DSM-5.* American Psychiatric Publishing.

Arnsten, A. F. T. (1998). Catecholamine modulation of prefrontal cortical cognitive function. *Trends in Cognitive Sciences*, 2(11), 436–447. https://bit.ly/3Q2Z4tC

Baddeley, A. (1996) Exploring the Central Executive. The Quarterly Journal of Experimental Psychology: Section A, 49, 5-28.https://bit.ly/3Qvw0fO

Balleine, B. W., Delgado, M. R., & Hikosaka, O. (2007). The role of the dorsal striatum in reward and decision-making: Figure 1. *The Journal of Neuroscience*, 27(31), 8161–8165. https://bit.ly/49702hc

Bartsch, T., Döhring, J., Reuter, S., Finke, C., Rohr, A., Brauer, H., Deuschl, G., & Jansen, O. (2015). Selective neuronal vulnerability of human hippocampal CA1 neurons: Lesion evolution, temporal course, and pattern of hippocampal damage in diffusion-weighted Mr Imaging. *Journal of Cerebral Blood Flow & Metabolism*, 35(11), 1836–1845. https://bit.ly/474QuS9

Bjorklund, D. F., & Harnishfeger, K. K. (1990). The resources construct in cognitive development: Diverse sources of evidence and a theory of inefficient inhibition. *Developmental Review*, 10(1), 48–71. https://bit.ly/3QdqLjy

Bjorklund, D. F., & Harnishfeger, K. K. (1995). The evolution of inhibition mechanisms and their role in human cognition and behavior. *Interference and Inhibition in Cognition*, 141–173. https://bit.ly/45QUODn

Blihar, D., Crisafio, A., Delgado, E., Buryak, M., Gonzalez, M., & Waechter, R. (2021). A meta-analysis of hippocampal and amygdala volumes in patients diagnosed with Dissociative Identity disorder. *Journal of Trauma & Dissociation*, 22(3), 365–377. https://bit.ly/45NfpZx

Blihar, D., Delgado, E., Buryak, M., Gonzalez, M., & Waechter, R. (2020). A systematic review of the Neuroanatomy of Dissociative Identity disorder. *European Journal of Trauma & Dissociation*, 4(3), 100148. https://bit.ly/46L31dC

Brand, B. L., McNary, S. W., Myrick, A. C., Classen, C. C., Lanius, R., Loewenstein, R. J., Pain, C., & Putnam, F. W. (2013). A longitudinal naturalistic study of patients with dissociative disorders treated by community clinicians. *Psychological Trauma: Theory, Research, Practice, and Policy*, 5(4), 301–308. https://bit.ly/3FB4Spm

Brand, B. L., & Lanius, R. A. (2014). Chronic complex dissociative disorders and borderline personality disorder: Disorders of emotion dysregulation? *Borderline Personality Disorder and Emotion Dysregulation*, 1(1), 13. https://bit.ly/3tO4ZeT

Brand, B. L., Sar, V., Stavropoulos, P., Krüger, C., Korzekwa, M., Martínez-Taboas, A., & Middleton, W. (2016). An Empirical Examination of Six Myths About Dissociative Identity Disorder. *Harvard Review of Psychiatry*. 2016 Jul-Aug;24(4):257-70. https://bit.ly/45Ldjcr

Chalavi, S., Vissia, E. M., Giesen, M. E., Nijenhuis, E. R. S., Draijer, N., Barker, G. J., Veltman, D. J., & Reinders, A. A. T. S. (2015). Similar cortical but not subcortical gray matter abnormalities in women with posttraumatic stress disorder with versus without dissociative identity disorder. *Psychiatry Research: Neuroimaging*, 231(3), 308–319. https://bit.ly/3Qe7cHM

Chalavi, S., Vissia, E. M., Giesen, M. E., Nijenhuis, E. R. S., Draijer, N., Cole, J. H., Dazzan, P., Pariante, C. M., Madsen, S. K., Rajagopalan, P., Thompson, P. M., Toga, A. W., Veltman, D. J., & Reinders, A. A. T. S. (2015). Abnormal hippocampal morphology in dissociative identity disorder and post-traumatic stress disorder correlates with childhood trauma and dissociative symptoms. *Human Brain Mapping*, 36(5), 1692–1704. https://bit.ly/3tNogwY

Cudzik, M., Soroka, E., & Olajossy, M. (2019). Dissociative identity disorder as a wide range of defense mechanisms in children with a history of early childhood trauma. *Current Problems of Psychiatry*, 20, 117-129.

Daumas, S., Halley, H., Francés, B., & Lassalle, J.-M. (2005). Encoding, consolidation, and retrieval of contextual memory: Differential involvement of dorsal CA3 and CA1 hippocampal subregions. *Learning & Memory*, 12(4), 375–382. https://bit.ly/45KBwjd

Dimitrova, L., Fernando, V., Vissia, E. M., Nijenhuis, E. R., Draijer, N., & Reinders, A. A. (2020). Sleep, trauma, Fantasy and cognition in Dissociative Identity Disorder, post-traumatic stress disorder and healthy controls: A replication and extension study. *European Journal of Psychotraumatology*, 11(1). https://bit.ly/3s2HIW3

Dimitrova, L. I., Dean, S. L., Schlumpf, Y. R., Vissia, E. M., Nijenhuis, E. R.,

Chatzi, V., Jäncke, L., Veltman, D. J., Chalavi, S., & Reinders, A. A. (2023). A neurostructural biomarker of Dissociative amnesia: A hippocampal study in dissociative identity disorder. *Psychological Medicine*, 53(3), 805–813. https://bit.ly/3seVbdf

Dorahy, M. J., Irwin, H. J., & Middleton, W. (2004). Assessing markers of working memory function in dissociative identity disorder using neutral stimuli: A comparison with clinical and general population samples. *Australian and New Zealand Journal of Psychiatry*, 38(1–2), 47–55. https://bit.ly/3SduZKT

Dorahy, M. J., Middleton, W., & Irwin, H. J. (2005). The effect of emotional context on cognitive inhibition and attentional processing in dissociative identity disorder. *Behaviour Research and Therapy*, 43(5), 555–568. https://bit.ly/3Qe737c

Dorahy, M. J., Lewis, C. A., & Mulholland, C. (2005). The detection of dissociative identity disorder by Northern Irish clinical psychologists and psychiatrists: a clinical vignettes study. *Journal of trauma & dissociation : the official journal of the International Society for the Study of Dissociation (ISSD)*, 6(4), 39–50. https://bit.ly/40bs2fJ

Dorahy, M. J., McCusker, C. G., Loewenstein, R. J., Colbert, K., & Mulholland, C. (2006). Cognitive inhibition and interference in Dissociative Identity disorder: The effects of anxiety on specific executive functions. *Behaviour Research and Therapy*, 44(5), 749–764. https://bit.ly/46Lol2G

Dorahy, M. J., Brand, B. L., Şar, V., Krüger, C., Stavropoulos, P., Martínez-Taboas, A., Lewis-Fernández, R., & Middleton, W. (2014). Dissociative identity disorder: An empirical overview. *Australian & New Zealand Journal of Psychiatry*, 48(5), 402–417. https://bit.ly/3Qwq3iM

Dubester, K. A., & Braun, B. G. (1995). Psychometric Properties of the dissociative experiences scale. *The Journal of Nervous and Mental Disease*, 183(4), 231–235. https://bit.ly/45FLoLb

Ehling, T., Nijenhuis, E. R. S., & Krikke, A. P. (2007). Volume of discrete brain structures in complex dissociative disorders: Preliminary findings. *Progress in Brain Research*, 307–310. https://bit.ly/4079qxv

Elzinga, B. M., Ardon, A. M., Heijnis, M. K., De Ruiter, M. B., van Dyck, R., & Veltman, D. J. (2006). Neural correlates of enhanced working-memory performance in dissociative disorder: A functional MRI study. *Psychological Medicine*, 37(2), 235–245. https://bit.ly/3MhBDMi

Felmingham, K., Kemp, A. H., Williams, L., Falconer, E., Olivieri, G., Peduto, A., & Bryant, R. (2008). Dissociative responses to conscious and non-conscious fear impact underlying brain function in post-traumatic stress disorder. *Psychological Medicine*, 38(12), 1771–1780. https://bit.ly/3Q9jz8b

Fine, C. G., & Berkowitz, A. S. (2001). The wreathing protocol: The imbrication

of hypnosis and EMDR in the treatment of Dissociative Identity disorder and other dissociative responses. *American Journal of Clinical Hypnosis*, 43(3–4), 275–290. https://bit.ly/3FwmUJz

Foote, B., & van Orden, K. (2016). Adapting dialectical behavior therapy for the treatment of Dissociative Identity disorder. *American Journal of Psychotherapy*, 70(4), 343–364. https://bit.ly/3tIEOWR

Forrest, K. A. (2001). Toward an etiology of dissociative identity disorder: A Neurodevelopmental approach. *Consciousness and Cognition*, 10(3), 259–293. https://bit.ly/40cCyDB

Frewen, P., & Lanius, R. A. (2015). *Healing the traumatized self: Consciousness, neuroscience, treatment.* W.W Norton & Company.

Freyd, J. J., & Deprince, A. P. (2001). Perspectives on memory for trauma and cognitive processes associated with dissociative tendencies. *Journal of Aggression, Maltreatment & Trauma*, 4(2), 137–163. https://bit.ly/495GZE5

Frischholz, E. J., Lipman, L. S., Braun, B. G., & Sachs, R. G. (1992). Psychopathology, hypnotizability, and dissociation. *The American journal of psychiatry*, 149(11), 1521–1525. https://bit.ly/4072ccN

Loewenstein R. J. (1991). Rational psychopharmacology in the treatment of multiple personality disorder. *The Psychiatric clinics of North America*, 14(3), 721–740

Gentile, J. P., Dillon, K. S., & Gillig, P. M. (2013). Psychotherapy and pharmacotherapy for patients with dissociative identity disorder. *Innovations in clinical neuroscience*, 10(2), 22–29

Grillon, C., Lissek, S., Rabin, S., McDowell, D., Dvir, S., & Pine, D. S. (2008). Increased anxiety during anticipation of unpredictable but not predictable aversive stimuli as a psychophysiologic marker of panic disorder. *American Journal of Psychiatry*, 165(7), 898–904. https://bit.ly/3QuYkin

Guralnik, O., Schmeidler, J., & Simeon, D. (2000). Feeling unreal: Cognitive processes in Depersonalization. *American Journal of Psychiatry*, 157(1), 103–109. https://bit.ly/3FwrffP

Hartmann, E., & Benum, K. (2019). Rorschach Assessment of Two Distinctive Personality States of a Person With Dissociative Identity Disorder. *Journal of personality assessment*, 101(2), 213–228. https://bit.ly/3Qv8v5F

Hallion, L. S., Steinman, S. A., Tolin, D. F., & Diefenbach, G. J. (2018). Psychometric properties of the difficulties in Emotion Regulation Scale (DERS) and its short forms in adults with emotional disorders. *Frontiers in Psychology*, 9. https://bit.ly/3Q52HPU

Hoeboer, C. M., De Kleine, R. A., Molendijk, M. L., Schoorl, M., Oprel, D. A., Mouthaan, J., Van der Does, W., & Van Minnen, A. (2020). Impact of disso-

ciation on the effectiveness of psychotherapy for post-traumatic stress disorder: Meta-analysis. *BJPsych Open*, 6(3). https://bit.ly/46KWL5B

Holaway, R. M., Heimberg, R. G., & Coles, M. E. (2006). A comparison of intolerance of uncertainty in analogue obsessive-compulsive disorder and generalized anxiety disorder. Journal of Anxiety Disorders, 20(2), 158–174. https://bit.ly/45N8GyP

Houtepen, L. C., Vinkers, C. H., Carrillo-Roa, T., Hiemstra, M., van Lier, P. A., Meeus, W., Branje, S., Heim, C. M., Nemeroff, C. B., Mill, J., Schalkwyk, L. C., Creyghton, M. P., Kahn, R. S., Joëls, M., Binder, E. B., & Boks, M. P. (2016). Genome-wide DNA methylation levels and altered cortisol stress reactivity following childhood trauma in humans. *Nature Communications*, 7(1). https://bit.ly/3FuYQ9R

Huntjens, R. J., Rijkeboer, M. M., & Arntz, A. (2019). Schema therapy for dissociative identity disorder (DID): Rationale and study protocol. *European Journal of Psychotraumatology*, 10(1). https://bit.ly/3QvfVa3

International Society for the Study of Trauma and Dissociation (2011) Guidelines for Treating Dissociative Identity Disorder in Adults, Third Revision, *Journal of Trauma & Dissociation*, 12:2, 115-187, https://bit.ly/3tMHwdW

Irle, E., Lange, C., Weniger, G., & Sachsse, U. (2007). Size abnormalities of the superior parietal cortices are related to dissociation in borderline personality disorder. *Psychiatry Research: Neuroimaging*, 156(2), 139–149. https://bit.ly/3Fzf8Pb

Johnston, W. A., & Dark, V. J. (1986). Selective attention. *Annual Review of Psychology*, 37(1), 43–75. https://bit.ly/475TH3M

Kluft, R. P. (1999). An overview of the psychotherapy of Dissociative Identity disorder. *American Journal of Psychotherapy*, 53(3), 289–319. https://bit.ly/46Gkxje

Lanius, R. A., Vermetten, E., Loewenstein, R. J., Brand, B., Schmahl, C., Bremner, J. D., & Spiegel, D. (2010). Emotion modulation in PTSD: Clinical and neurobiological evidence for a dissociative subtype. *American Journal of Psychiatry*, 167(6), 640–647. https://bit.ly/4761vTs

Linehan, M. M., Comtois, K. A., Murray, A. M., Brown, M. Z., Gallop, R. J., Heard, H. L., Korslund, K. E., Tutek, D. A., Reynolds, S. K., & Lindenboim, N. (2006). Two-year randomized controlled trial and follow-up of dialectical behavior therapy vs therapy by experts for suicidal behaviors and borderline personality disorder. *Archives of General Psychiatry*, 63(7), 757. https://bit.ly/3QwAK55

Leonard, D., Brann, S., & Tiller, J. (2005). Dissociative disorders: pathways to diagnosis, clinician attitudes and their impact. *The Australian and New Zealand journal of psychiatry*, 39(10), 940–946. https://bit.ly/495G9ap

Marchwicki, P. (2004). Osobowość wieloraka. Kryteria diagnostyczne I modele etiologiczne, *Seminare. Poszukiwania naukowe*, 20, 357-368.

Merker, J. B., Hill, S. B., Wolff, J. D., Winternitz, S. R., Ressler, K. J., Kaufman, M. L., & Lebois, L. A. M. (2021). Posttraumatic cognitions predict distorted body perceptions in women with Dissociative Identity disorder. *Journal of Psychiatric Research*, 134, 166–172. https://bit.ly/45KK21t

Miller, A. L. (2015). Introduction to a special issue dialectical behavior therapy: Evolution and adaptations in the 21st century. *American Journal of Psychotherapy*, 69(2), 91–95. https://bit.ly/3s4SzPe

Mitra, P., & Jain, A. (2023). Dissociative Identity Disorder. In *StatPearls*. StatPearls Publishing

Neill, W. T., Valdes, L. A., & Terry, K. M. (1995). Selective attention and the inhibitory control of cognition. *Interference and Inhibition in Cognition*, 207–261. https://bit.ly/3Q8QLfX

Nijenhuis, E. R., van der Hart, O., & Steele, K. (2002). The emerging psychobiology of trauma-related dissociation and dissociative disorders. *Biological Psychiatry*, 1079–1098. https://bit.ly/460Q5zr

Nijenhuis, E. R., & van der Hart, O. (2011). Dissociation in trauma: A new definition and comparison with previous formulations. *Journal of Trauma & Dissociation*, 12(4), 416–445. https://bit.ly/3MhwfIS

Nijenhuis, E. R. S. (2015). *The Trinity of Trauma: Ignorance, fragility, and control: The evolving concept of trauma/the concept and facts of dissociation in trauma.* Vandenhoeck & Ruprecht.

Okon-Singer, H., Hendler, T., Pessoa, L., & Shackman, A. J. (2015). The neurobiology of emotion-cognition interactions: Fundamental questions and strategies for future research. *Frontiers in Human Neuroscience*, 9. https://bit.ly/3FycCbK

Perniciaro, L.A. (2014). The Influence of Skepticism and Clinical Experience on the Detection of Dissociative Identity Disorder by Mental Health Clinicians

Pietkiewicz, I. J., Bańbura-Nowak, A., Tomalski, R., & Boon, S. (2021). Revisiting False-Positive and Imitated Dissociative Identity Disorder. *Frontiers in psychology*, 12, 637929. https://bit.ly/3tSa19Y

Pruthi, G. K. (2018). Managing dissociative disorder with Cognitive Behaviour Therapy: A case study. *International Journal of Indian Psychology*, 6(4). https://bit.ly/494Xyjx

Reategui, A.(2019). Dissociative identity disorder: A literature review. *Undergraduate Journal of Psychology*, 31(1), 22-27

Reinders, A. A. T. S., Willemsen, A. T. M., den Boer, J. A., Vos, H. P. J., Veltman, D. J., & Loewenstein, R. J. (2014). Opposite brain emotion-regulation patterns in identity states of Dissociative Identity disorder: A PET study and neurobiological model. *Psychiatry Research: Neuroimaging*, 223(3), 236–243.

https://bit.ly/3Q7HgOd

Reinders, A. A. T. S., Willemsen, A. T. M., Vissia, E. M., Vos, H. P. J., den Boer, J. A., & Nijenhuis, E. R. S. (2016). The psychobiology of authentic and simulated dissociative personality states. *Journal of Nervous & Mental Disease*, 204(6), 445–457. https://bit.ly/3s89u3u

Reinders, A. A., Chalavi, S., Schlumpf, Y. R., Vissia, E. M., Nijenhuis, E. R., Jäncke, L., Veltman, D. J., & Ecker, C. (2017). Neurodevelopmental origins of abnormal cortical morphology in dissociative identity disorder. *Acta Psychiatrica Scandinavica*, 137(2), 157–170. https://bit.ly/3S8tspj

Reinders, Antje A., Marquand, A. F., Schlumpf, Y. R., Chalavi, S., Vissia, E. M., Nijenhuis, E. R., Dazzan, P., Jäncke, L., & Veltman, D. J. (2018). Aiding the diagnosis of dissociative identity disorder: Pattern recognition study of brain biomarkers. *British Journal of Psychiatry*, 215(3), 536–544. https://bit.ly/49b1DTw

Reinders, Antje A., Dimitrova, L. I., Schlumpf, Y. R., Vissia, E. M., Nijenhuis, E. R., Jäncke, L., Chalavi, S., & Veltman, D. J. (2022). Normal amygdala morphology in dissociative identity disorder. *BJPsych Open*, 8(2). https://bit.ly/3QsZU4m

Sar, V., Unal, S. N., & Ozturk, E. (2007). Frontal and occipital perfusion changes in dissociative identity disorder. *Psychiatry Research: Neuroimaging*, 156(3), 217–223. https://bit.ly/3Qxm2KQ

Sar, V., Onder, C., Kilincaslan, A., Zoroglu, S. S., & Alyanak, B. (2014). Dissociative identity disorder among adolescents: prevalence in a university psychiatric outpatient unit. *Journal of trauma & dissociation : the official journal of the International Society for the Study of Dissociation (ISSD)*, 15(4), 402–419. https://bit.ly/3MhXuDf

Sar, V., Dorahy, M., & Krüger, C. (2017). Revisiting the etiological aspects of Dissociative Identity disorder: A biopsychosocial perspective. *Psychology Research and Behavior Management*, Volume 10, 137–146. https://bit.ly/3Fv3C7h

Schlumpf, Y. R., Nijenhuis, E. R. S., Chalavi, S., Weder, E. V., Zimmermann, E., Luechinger, R., La Marca, R., Reinders, A. A. T. S., & Jäncke, L. (2013). Dissociative part-dependent biopsychosocial reactions to backward masked angry and neutral faces: An fmri study of Dissociative Identity disorder. *NeuroImage: Clinical*, 3, 54–64. https://bit.ly/3QtVDxM

Schore, A. N. (2012). *Affect regulation and the origin of The self: The neurobiology of emotional development.* Psychology Press.

Schwabe, L., Dalm, S., Schächinger, H., & Oitzl, M. S. (2008). Chronic stress modulates the use of spatial and stimulus-response learning strategies in mice and man. *Neurobiology of Learning and Memory*, 90(3), 495–503. https://bit.ly/47mYUVl

Siegel, A., & Sapru, H. N. (2015). *Essential neuroscience.* Wolters Kluwer.

Steele, K., Boon, S., & der, H. O. van. (2016). *Treating trauma-related dissociation: A practical, integrative approach.* W. W. Norton & Company.

Stoffers-Winterling, J. M., Völlm, B. A., Rücker, G., Timmer, A., Huband, N., & Lieb, K. (2012). Psychological therapies for people with borderline personality disorder. *Cochrane Database of Systematic Reviews*, 2020(9). https://bit.ly/3MeV4FB

Taïb, S., Yrondi, A., Lemesle, B., Péran, P., & Pariente, J. (2023). What are the neural correlates of dissociative amnesia? A systematic review of the functional neuroimaging literature. *Frontiers in Psychiatry*, 14. https://bit.ly/3Mfv6S8

Tipper, S. P., Bourque, T. A., Anderson, S. H., & Brehaut, J. C. (1989). Mechanisms of attention: A developmental study. *Journal of Experimental Child Psychology*, 48(3), 353–378. https://bit.ly/408sGug

van der Hart, O., Nijenhuis, E. R. S., & Steele, K. (2006). *The haunted self: Structural dissociation and the treatment of chronic traumatization.* New York: W. W. Norton.

van Minnen, A., & Tibben, M. (2021). A brief cognitive-behavioural treatment approach for PTSD and Dissociative Identity Disorder, a case report. *Journal of Behavior Therapy and Experimental Psychiatry*, 72, 101655. https://bit.ly/3tSyYlD

Vissia, E. M., Lawrence, A. J., Chalavi, S., Giesen, M. E., Draijer, N., Nijenhuis, E. R., Aleman, A., Veltman, D. J., & Reinders, A. A. (2022). Dissociative identity state-dependent working memory in Dissociative Identity disorder: A controlled functional magnetic resonance imaging study. *BJPsych Open*, 8(3). https://bit.ly/49joZGy

Vermetten, E., Schmahl, C., Lindner, S., Loewenstein, R. J., & Bremner, J. D. (2006). Hippocampal and amygdalar volumes in dissociative identity disorder. *The American journal of psychiatry*, 163(4), 630–636. https://bit.ly/46Gkrbm

Weniger, G., Lange, C., Sachsse, U., & Irle, E. (2008). Amygdala and hippocampal volumes and cognition in Adult Survivors of Childhood Abuse with Dissociative Disorders. *Acta Psychiatrica Scandinavica*, 118(4), 281–290. https://bit.ly/45NfFYv

Wilson, S. P., & Kipp, K. (1998). The development of efficient inhibition: Evidence from directed-forgetting tasks. *Developmental Review*, 18(1), 86–123. https://bit.ly/45PWc9s

Zhong, Y.-M., Yukie, M., & Rockland, K. S. (2005). Distinctive morphology of hippocampal CA1 terminations in orbital and medial frontal cortex in macaque monkeys. *Experimental Brain Research*, 169(4), 549–553. https://bit.ly/3sbX2PZ

Helping Scientific Researchers Make Better Use of Ontologies
Tools, Methods and Best Practices

Gary Berg-Cross and James A. Overton

Abstract

The idea of using ontologies and other related/semantic resources to improve computing has long existed, with many initiatives to develop methods and tools that could be widely employed by the scientific community. While the effort to develop and use ontologies has matured, many barriers remain to help typical end-user researchers develop and employ ontologies. These include questions related to how to initiate the development of an ontology, what tools to use, and how to maintain an ontology after its development. In addition, it is difficult for domain users and data specialists to express and maintain knowledge represented in formal languages such as first order logic and or OWL for ontologies. Motivated in part by the influence of big data and the widespread adoption of FAIR principles that encourage the use of formal semantics, this communiqué provides an overview of the current environment of ontological methods and the tools and best practices across the ontology development lifecycle. The communiqué concludes with a list of current challenges that require continued research. While the emphasis is on bio-ontology tools, ontology technologies can be applied to other disciplines as diverse as the Earth sciences and finance, or have more general use such as in knowledge graphs.

Introduction

Early ontology summits, such as the Ontology Summit 2007 "Ontology, Taxonomy, Folksonomy: Understanding the Distinctions", have attempted to explain the value of ontologies and related semantic resources. The have also provided guidance on usage as found, for example, in the Ontology Usage Framework (2011) co-championed by Michael Grüninger, Michael Uschold, and Nicola Guarino. This guidance is also useful for other artifacts such as terminologies, thesauri and vocabularies, collectively known as knowledge organization systems, that can be used to annotate data. Even these early efforts on ontology development made clear that building, maintaining, and using an ontology is an iterative process that often calls for ongoing collaboration and communication between stakeholders, domain experts, and ontology developers. With Big Data, open and

well managed community ontologies are increasingly important for open science (Bennett and Baclawski, 2017; Musen et al., 2018).

There is now a growing commitment to data sharing from scientific researchers and universities (Sorbonne Declaration, 2020). This commitment has been codified in the Findable, Accessible, Interoperable, and Reusable (FAIR) guidelines (Wilkinson et al., 2016). Ontologies and semantic approaches can facilitate some of the FAIR guidelines, which emphasize machine-actionability (i.e., the capacity of computational systems to find, access, interoperate, and reuse data with none or minimal human intervention) (FAIR Principles, n.d.). Among other things, a principled use of semantics would facilitate the creation of metadata documentation needed to support data repositories. Much day-to-day work can involve working with data scientists to make the data FAIR and address the challenges of many formats and using ontologies. How do we make the concepts easier to use? Too often, some of the semantic aspects of FAIR are particularly difficult for scientists. Furthermore, the idea of extending FAIRness to ontologies would obviously be useful, but the challenge is how to do so. Issues of grounding ontologies into deeper semantics raise foundational issues. The work of the OBO Foundry (OBO Foundry, 2023), for example, demonstrates how "a sizable, federated community can be organized and evaluated on objective criteria that help improve overall quality and interoperability, which is vital for the sustenance of the OBO project and towards the overall goals of making data FAIR." (Jackson et al., 2021).

We begin this communiqué with a section on defining the problems that are encountered by scientists when confronted with assuring compliance with the enhanced semantics requirements of the FAIR guidelines, particularly with respect to ontologies and other semantic resources. In practice, the actual development, maintenance, coordination, and use of ontologies and other semantic resources in science remains complex because of the reliance on a sophisticated interconnected web of tools, methodologies, standards, various knowledge artifacts and community practices, at the intersection of science, software development, and information management. While the semantic community increasingly understands how to address some of these challenges, the larger community of scientists and researchers often do not.

The main sections of communiqué give an introduction and overview to the many methods, tools and resources that have been developed by the semantic community. Specifically, the sections are:

Methodologies We start with the basics of ontology development (Noy and McGuinness, 2001; Noy et al., 2010) and show how basic engineering has advanced over time to be more socio-technical in nature (recognizing the impact on people as well as the technical aspect).

Resources As with software development in general, one starting point for ontology development is to reuse existing ontologies.

Techniques A large variety of techniques are available for ontology design tasks, including customizable forms such as design patterns, templates, modular modeling, as well as upper level domain ontologies.

Tools There are many tools for managing the later phases of ontology development as well as ontology maintenance and use. This section describes a selection of such tools.

Knowledge Graphs A knowledge graph (KG) is both a knowledge representation language and a knowledge system that helps to organize and structure data and information in a way that is can be easy to understand, search and navigate. Mapping ontologies to KGs can help ensure that the both data and ontologies satisfy the FAIR guidelines.

A simple, running example illustrates the nature of the work. Note that only a sample of methodologies, tools, and models (e.g., ontologies) are provided, such as those mentioned in the Summit presentations. The reader is encouraged to research the broader global content on these topics.

The communiqué ends with conclusions and recommendations for continued research efforts. The appendices provide a glossary of important terminology and scenarios. Our goal is to help scientific researchers and other practitioners to take advantage of the many tools and techniques that have been developed by the ontology community to make better use of ontologies.

Defining the Problem

There have been many discussions in online forums and academic conferences on the challenges of ontologies. Interested users or developers often voice concerns about problems and obstacles preventing them from achieving a satisfactory level of competency, particularly on semantic topics. A recent Earth Science Information Partners (ESIP) workshop "Semantics Adoption in the Earth and Environmental Sciences: Successes and Roadblocks" organized in January 2023 by the ESIP Semantic Harmonization co-leads Gary Berg-Cross and Ruth Duerr, identified several issues that were preventing people from getting started with, or using, semantics more in their work. These included technical issues such as difficulties with formal logical languages. Some of the activities do not make sense to non-ontologists.[1] Others are caused by starting points with captured knowledge that is too informal, may allow duplicates in tools like spreadsheets (an issue for populating knowledge graphs for example), allows ad hoc creation of classes with no thought of referential integrity (Alani, Harith et al., 2002) or allowing a wide variety of schemas to express the same or similar knowledge. Each of these makes FAIR interoperability of data resources difficult. Similar aspects were the subject of last year's summit on Disasters (Sharma et al., 2022).

Domain size and (in the context of manual development tasks) the repetitive nature of adding entities are also well-known challenges. It is important that an ontology supports a large number of classes, many of which may have similar structure so basic ontology editing tools such as Protégé can frustrate users. Repetitive tasks are often painstaking, and spreading editing over multiple people can introduce errors. Sometimes collaboration makes editing worse (Skjæveland, 2023).

There are only a few examples of mature technological support for most ontology engineering methodologies. Generally many tools are available, but often are: too technical and low-level for non-programmer use; not mature; not widely adopted; or poorly integrated with other ontology tools or with common Integrated Development Environment (IDE) envi-

[1]The ontology community published recommendations for the body of knowledge that an ontologist should learn and the skills that an ontologies should acquire in Neuhaus and Smith (2010) and Neuhaus et al. (2011).

ronments.

Overall, IDE tooling is currently insufficient for ontology development. The development phase of ontologies requires better approaches than currently available for visualization of models and help in conceptual modeling, a challenge long recognized in knowledge engineering (Katifori et al., 2007). To some the importance of a conceptual solution, and the lack of adequate diagrams is more of a problem than challenges of OWL representation or exact serialization. Semantic solutions (Fürber and Fürber, 2016) must be human-understandable, requiring the need to handle and hide complexity using methods and tools that maintain full logical axiomatization "in the background." The Open Ontology Repository concept was discussed in the Ontology Summit 2008 and requires infrastructure support for the sustainable repositories of interoperable or stand alone mature ontologies (Obrst and Musen, 2008).

Problem size is evidenced in the comment at the ESIP discussion of semantic issues, "Designing a query to find ALL chemical participants in a biological process is too hard." In some cases, there are misconceptions about semantics itself or its role in supporting data management, metadata tagging, and data interoperability. Examples of misunderstanding include: "There needs to be one ontology." or "Semantics is not robust enough to describe data to the level needed for data integration/harmonization" to "I can find ontologies online, but how do I know whether they are endorsed by the scientific community?" or "The real word is fuzzy, semantic systems are primarily discrete." Other types of problems deal with programmatics or are organizational such as "How do I start (a project)?" or "Our funding models are broken." Still others were "I am not sure where to start" or expressed practical needs for, "Practical applications bringing all this work to bear on discovery for busy scientists" or "if I search on a term it may appear in a couple places in the ontology." There are simple complaints such as "How do I make sure that whenever I make a change, I didn't break anything?" or "I feel like I have to create rules for how to choose between different ontologies. Lots of work." Interoperability and ease of use appear to be the needed facilitators for easy adoption among others.

A common problem concerns how to start the development of an ontology. The experience of the OBO Foundry is that it is difficult to

attract and keep end-users productively involved, which is important for building and maintaining large ontologies.

Once an ontology development project has started, technical issues arise including language difficulties, consistent modeling and how to collaborate as well as automated support (Skjæveland, 2023).

Knowledge representation issues include questions on how to simplify OWL formalization. The well known Manchester syntax for OWL 2 ontologies represents coding at a too low level and can be difficult. Also challenging are tools that support work on conceptual modeling that will later form the basis of an ontology.

Methodologies

A simple, but well accepted, view of the ontology engineering process (Figure 1) was developed in 2001 and begins by determining the scope and uses of an ontology (Noy and McGuinness, 2001). This is followed by conceptualizing the ingredients of the ontology, including: identifying and enumerating the classes and properties that will be used to represent domain concepts and relationships of interest, considering relations that can be axiomatized as rules that will govern the logical behavior of the ontology. A formalization step using low level tools, such as Protégé, which is often difficult for domain researchers, follows conceptualization and involves selecting a formal language that will be used to logically represent the ontology. This may organize the classes into a hierarchy with subclasses, while also specifying their properties and interrelationships in a machine-readable format. Finally, the classes are populated with instances, yielding an ontology that is sometimes described as a knowledge base.

Proposed requirements for ontologies have grown over the last 20 years and now include more complex methods for things such as the uses of glossaries and templates, and the iterative maintenance of large, interrelated ontologies. This reflects the need to support:

- A large number of classes, potentially requiring collaborative community conversation. For example, there are millions of classes across more than two hundred OBO Foundry ontologies.
- A large number of standards and related semantic resources such as

Figure 1: Classic ontology development lifecycle (Noy and McGuinness, 2001)

glossaries. When compared, they may have apparently incompatible conceptualizations within the specified scope or universe of discourse.

- Semantically consistent modeling. There is also a need for a modeling that works for the same category of things in the same way, across different standards.
- Community collaboration with different levels of experience and interest. This can introduce problems. Some support is needed to make collaborative development easier.
- Contributions from varying backgrounds and competencies (technical and ontological), reflecting the fact that community models should be consistent across all contributors!
- Mechanisms to make the development process easier; for example, automated mechanisms for quality assessment and verification.

Taken together, these requirements reflect recent methodologies with a community focus and greater level of detail, and are worth considering to frame an understanding of modern ontological engineering. In contrast to earlier methods, approaches such as the NeOn methodology (Suárez-Figueroa et al., 2015) provide a richer lifecycle methodology founded on the four pillars listed below. It is useful for discussing a range of practices within ontological engineering phases. The NeOn Toolkit includes several Protégé plug-ins to aid the various activities in the ontology engineering process.

1. A glossary for activities in the methodology. This aids a user in understanding the terms used. Appendix 1 is an example of a glossary.
2. A set of scenarios for building ontologies and ontology networks. Appendix 2 is an example of a set of scenarios and a supporting figure.
3. A waterfall, but also an iterative ontology life-cycle model. An iterative life-cycle may be seen to support ontologies whose scope helps to represent a dynamic domain (e.g, healthcare) which is modeled over time.
4. A set of prescriptive methodological guidelines for performing specific activities. These guidelines can aid in obtaining and re-using terms from external ontologies.

Ideas on how to engineer ontologies go well beyond technical elements are increasingly socio-technical in that the overall process requires ongoing collaboration and tool-use as well as communication between stakeholders, domain experts, and developers.

The following steps are socio-technical best practices that can help avoid commonly occurring ontological errors and can help format and refine domain terminology (Rudnicki, Smith, Malyuta, and Mandrick, 2016):

1. Form a team. Ensure your team includes both subject matter experts familiar with both subject-matter (the entities in your domain) and data (the information resources that the ontology will be used to integrate and analyze and to make discoverable).
2. Ensure that your team includes persons with ontology-building experience. (Facility with ontology software does not imply the ability to create ontologies.)
3. Identify the primary tasks your ontology will be designed to realize.
4. Identify the domain of your ontology – the types of objects and attributes and processes which the ontology will need to represent.
5. Identify the primary bodies of data your ontology will be used to annotate.
6. Be aware that your goal is to maximize the ability of your ontology to address these primary tasks but without detriment to its ability to address secondary uses not yet identified. (Experience shows that

secondary uses are often significantly more important than primary uses, and that secondary uses are almost always what guarantees the enduring value of an ontology.)[2]

In NeOn, the requirements phase and team-building activities are followed by a phase in which reuse is considered. This phrase may include a search and evaluation of non-ontological resources (NOR), such as glossaries with terms defined for human understanding but not axiomatized for automated processing. Proper selection of these resources may help ensure grounding in domain concepts already used by a community as part of communication. Note, however, that the reuse of either (non)ontological resources does not in itself ensure consistency or implementation of the intended semantics (Rovetto, 2023).

Several recent developments help illustrate the value of the second NeOn scenario in Appendix 2, Reusing and re-engineering non-ontological resources. Indeed, since there are many, diverse sources of data in different formats on the web having a standard source is useful. Wikidata, for example, is one that is a free and open non-ontological graph knowledge base with descriptions and qualified statements about uniquely identified entities and their properties such as people, places, things, and events in a similar form to RDF. The Wikidata graph is easily queried about data.

Although it does not include strict axiomatization and its knowledge may be shallow, Wikidata's concepts and relationships can be a useful source of ideas for ontology development. Since properties in Wikidata are community created, however, there is often no direct mapping to an ontology's property relation. Mapping to support interoperability between semantic resources is complex, but is aided by the use of Internationalized Resource Identifier (IRI) for identity and basic semantics. For example, there are some mappings of Wikidata terms to OBO Foundry ontologies including reuse of relationships based on a mix and match approach to aligning two independently developed semantic resources. Simple Knowledge Organization System (SKOS) relations such as "close match" can be

[2]The main strategy to ensure future-proofing against problems in addressing secondary uses is to ensure that the terms and definitions in your ontology are of broad understandability and validity (rather than being understandable and valid only by your immediate collaborators and only when used in relation to your currently available data).

used to document relations (Hoyt, Hoyt, and Gyori, 2023).

Science on Schema.org is another non-ontological resource designed to help scientists make their data more discoverable and accessible to others. To do this, Science on Schema.org provides common publishing patterns for describing research data guidelines about scientific datasets and resources using an extended Schema.org vocabulary. Essentially, it is a metadata schema with an extended vocabulary to consistently describe data and related material such as temporal and spatial coverage, or people's roles in data. Science on Schema.org takes a step toward interoperability between vocabularies which in turn may be a resource for the ontology population.

Guidelines for starting with NOR cover a wide range of topics, including:

- How to describe the different types of scientific data
- How to provide links to related resources
- How to use Schema.org properties to describe the data

An important benefit of using Science on Schema.org is increased data interoperability and reusability with modest formal semantics that can be further aligned to ontologies as needed. Domain work between projects runs into interoperability challenges across ontologies that need to be monitored, including the variation in terms and relations, metadata documentation, how responses are managed to make changes and how to control the chaos in ontology prefixes.

Data models themselves can be a useful non-ontological sources of information. The Linked Data Modeling Language is a data modeling framework that can be used to describe many kinds of data models: from value sets and flat, checklist-style standards to complex normalized data structures that use polymorphism and inheritance (LinkML, n.d.). LinkML is designed so that software engineers and subject matter experts can communicate effectively in the same language, while also providing the semantic underpinnings to make data conforming to LinkML schemas easier to understand and reuse computationally in the semantic web. The LinkML metamodel provides the ability to map a model class or attribute to an existing ontology class (via SKOS exact, narrow, related, etc. mappings), to a

set of ontology classes (via semantic enumerations), and/or to declare that the URI for a model class or attribute is exactly the URI for an existing ontology class.

Additionally, the LinkML framework includes tools to serialize data models in many formats including, but not limited to: JSONSchema, OWL, RDF, SQL-DDL, and Python Pydantic classes. It also includes tools to help convert both instance and class data from one model serialization (like YAML) to a different model serializations (such as OWL). LinkML provides validation software at both the instance and schema level, software to navigate and query model metadata (via LinkML schema view), and tools to bootstrap a LinkML schema from another framework (LinkML schema automator). In addition, it can auto-generate documentation and schema diagrams.

Other ontology development methodologies, or approaches for development methods, include Agile methods, and the Methontology methodology which may be a precursor version of NeON.

Resources

All of the ontology engineering methods begin with either reuse of existing ontologies or bespoke development of new ontologies. If the starting point is to reuse existing ontologies, then candidate ontologies are analyzed and evaluated for suitability, as discussed in NeOn Scenario 3. Choices must be made because a given domain or topic can be modeled in various ways, resulting in distinct yet equally-valid ontologies. Candidate ontologies may be open-source or proprietary and available for purchase. Identifying the appropriate ontology for a specific task can be challenging, especially for those who are not familiar with the task; however, ontology repositories now exist with searchable collections. Some examples include the following.

- Linked Open Vocabularies (LOV) provides a curated collection of vocabularies, broadly construed to include ontologies (Linked Open Vocabularies, n.d.)
- The OntoPortal application provides a means for creating repositories or libraries. BioPortal for example, has various biological and medical ontologies (Bioportal, n.d.).

- The OBO Foundry, a library of biomedical ontologies, covers a wide range of topics, including from Biology (genes, proteins, cells, tissues, organs, and organisms) to Biomedicine covering diseases, symptoms, treatments, and procedures; to chemicals, compounds, and reactions; ecological information about for organisms, habitats, and ecosystems. However, the requirements for being included in this library may be more restrictive or otherwise undesirable for some. In any (for any library or repository), requirements or criteria for inclusion should be evaluated and clearly understood. Note in passing that the Ontology Development Kit (ODK), developed by the OBO community, and covered in more detail in the Tools section below, is one tool that may be used to reuse an existing ontology and/or its parts.
- Another example of a library for reuse is MODL, a curated Modular Ontology Design Library (Shimizu, Hammar, and Hitzler, 2021). It has collected well-documented ontology design patterns, drawn from a wide variety of interdisciplinary use-cases. MODL contains over 100 ontology design patterns (ODPs), organized into several categories include basic patterns similar to OBO's templated OWL patterns such as metapatterns for the organization of data; space and time events; the movement; agents and roles; along with descriptive details such as quantities and units, partonymy/meronymy, provenance and identifiers. More on the role of ODPs is discussed in the Customizable Forms section below.

Techniques

The interoperability of data via ontologies is a key aspect of FAIR. However, ontologies developed for different domains also need to be interoperable. The biomedicine community is a good example of a community dealing with both data and ontological interoperability in a principled and practical way. The OBO Foundry's strategy has four levels. At the base level are things like common FAIR principles that allow ontologies to be found, accessed, reused supported by FAIR criteria such as IRIs and metadata that will allow a degree of interoperability. This is further supported at the next level up by agreement on common formats and the use of integrated tools, such as OWL tools like Protégé, and OWL API as well as higher-level development and management tools such as ROBOT en-

abling the ability to read and write ontologies in commonly understood formats. Level 3 focuses on community developed semantic resources such as shared vocabularies and upper level reference models that support standardization and integration between ontology modules. At the top (Level 4) are shared, general design patterns for building domain ontologies such as dead simple OWL design patterns (DOSOP, 2023) which are a simple templating system for documenting and generating new OWL classes. The templates themselves are designed to be human readable and easy to author. Separate tables (TSV files) are used to specify individual classes. ROBOT templates, and the Reasonable Ontology Templates (OTTR) are other templates that serve to develop general modeling patterns that can be used to start an ontology and share them across a community. In the following subsections, we discuss simplifying tools and techniques from the various levels as well as how they work together.

Customizable Forms

Ontology design templates (ODTs) and ontology design patterns (ODPs) are time-saving tools for an ontology designer by providing easily understood starting points for building a new ontology. The modular parts are designed to interoperate, thus improving the efficiency of the development process (Shimizu, C. Hitzler, P and Krisnadhi, 2020). ODTs and ODPs capture human conceptualization using a machine parseable constraint language (Hitzler and Shimizu, 2018). When selecting relevant templated patterns there are trade-offs to consider between generality and specificity. Abstract modeling patterns may provide a general structure for an ontology, as well as some of the basic concepts and relationships that are likely to be needed before use of more specific patterns. Together, they represent a useful middle ground between reusing a complete ontology and making a new one from scratch (Blomqvist et al., 2016).

OBO Patterns

The OBO Foundry encourages the adoption of a curated collection of rigorously defined and extensively validated OWL design patterns. These patterns, formulated by domain experts, bridge the gap between human conceptualization and the corresponding, known data instances. Frequently occurring patterns represent a common starting point that may help with consistency and interoperability between ontologies. The ODP schema

can impose structure on data, encoding relational knowledge so data may interoperate with other data that has been built from the same pattern.

Many OBO projects provide templates that allow for efficient sharing and reuse among developers, promoting collaborative efforts and facilitating ontology updating and maintenance. By implementing these templates, developers can construct ontologies with coherent semantics, seamless interoperability, and user-friendly accessibility.

More Complex Patterns

Some templated patterns cover and connect a larger number of concepts. An example is the Recurrent Event Series ODP that has 4 main concepts (Carriero et al., 2019):

1. Recurrent Event Series - A recurrent event series is a collection of events that recur at regular intervals.
2. Event - An event is a single occurrence that happens at a specific time and place.
3. Unifying Factor - A unifying factor is a property/characteristic that is shared by all the events in a recurrent event series.
4. Recurrence - Recurrence is the property of an event or event series that occurs at regular intervals.

Reasonable Ontology Templates

The templating language and toolkit used in OTTR is another example of how to simplify the process of structurally coding knowledge such as classes, properties, and individuals so they can be expressed in OWL (Skjæveland et al., 2018). These templates also represent the initial, general building blocks of the ontology and serve as the starting point for further refinement. Taken as a whole the OTTR approach helps:

- Avoid unnecessary repetition
- Encapsulate complexity
- Support uniform modeling
- Separate design and content

- Ensure input completeness via type checking and consistent use of IRIs
- Simplify input format (using parameters, expandable lists and macros)
- Support parameterized substitution and provides macro expansion similar to macro systems found in programming languages, where macros are used to define reusable code fragments that can be expanded into larger expressions or statements.

More detail on OTTRs and associated methods are summarized in Appendix 3.

Modular Ontology Modeling

The domain reference ontology discussed in more detail in the next subsection typically are composites that employ one or more patterns. These reflect integration of smaller modules and intended to be reusable as an artifact and not just a template (Hahmann, 2023). Indeed, modular ontology methods or "pattern-mediated methods" built around templated ODTs and ODPs represent a systematic, alternate approach for building up ontologies from meaningful smaller parts.

The idea is to start bottom-up from concepts which are then grouped together into larger modules. This views an ontology as made up of smaller, more manageable modules that are connected using special, compositional semantic relations. ODP structure also called "metadata scaffolding" can be used to represent background knowledge, improve alignment and provide a mechanism for improved reusability (Shimizu, Hammar, and Hitzler, 2023).

Modular solutions use tools, such as the previously discussed templates that understand key aspects of the ontology language (OWL, RDF, or RDFS). The Comprehensive Modular Ontology IDE (CoModIDE) is a plugin for Protégé that allows bringing together such modules produced in a 9 steps method listed below (Shimizu, Hammar, and Hitzler, 2019):

1. Define the use case
2. Write up competency questions
3. Identify key notions

4. Match patterns to key notions
5. Template-based instantiate the patterns
6. Systematic axiomatization
7. Assemble the modules
8. Review final product
9. Produce the OWL artifacts

An attraction to this method like templates themselves is that, in theory, ODPs provide a start on work for projects that lack some ontological expertise. The intent is to enable domain experts to reuse existing and tested best practices for design decisions. However, in practice the adaptation of ODPs as tools for ontology engineering by domain experts remains slow. (Krieg-Brückner, Mossakowski, and Codescu, 2021).

Upper Level Domain Models

Another starting point for ontology development is an upper level domain model. These models may be understood as broad but relatively domain-specific models. For example, the Core ontology for Biomedicine (COB) is a high-level ontology describing the Biomedical domain. It is motivated in part by a need for a simplified, user-friendly layer above application oriented ontologies at an intermediate level, but below a more abstract, general top level ontology such as the Basic Formal Ontology (BFO) as shown in Figure 2 (Otte, Beverley, and Ruttenberg, 2021). Some of the ideas supporting the use of a high level reference model include "upper level domain reference models" such as COB in the Biomedical area and HyFo (Hahmann, Stephen, and Brodaric, 2015), a foundation for hydrological flow dynamics, axiomatize deep knowledge of core domain concepts. This provides a solution-independent specification (e.g., a domain conceptualization) using a clear and precise description of domain entities at a level of detail such that other domain ontologies/standards including in applications can be expressed using this terminology. These have proven useful in interdisciplinary (domain, programming, data, metadata, semantic technology and ontological) community efforts.

Practical work needs something closer to a domain to organize concepts. An upper domain model like COB provides a central, consistent place where different ontologies (say within OBO) can discuss and agree

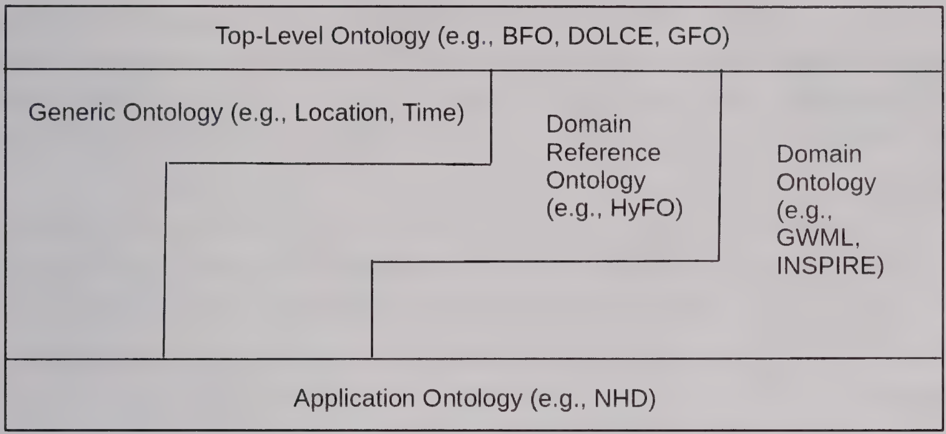

Figure 2: Types of ontologies, indicating where each type occurs within the class hierarchy (based on Hahmann, 2023)

where the different root terms across OBO (like mass) belong in the COB hierarchy. One advantage is that termed classes with the same semantics in different ontologies can be related as "equivalent" and IDs can be swapped out as needed. Another advantage is that COB can be modular, can use agreed-upon standardized relationships, and can have associated tools and community standardized best practice techniques, such as how to use metadata to annotate ontologies to manage it. Some of these tools are discussed the subsection below.

Tools

A major phase of work following reuse is the various conceptual and constructive activities that allow population and later implementation of an ontology in a logical language. This requires careful consideration of the relationships between concepts and entities. The process can be time-consuming and requires some level of expertise. Construction is a collaborative process which can be helped by tooling.

There are many tools to consider for population and later phases of work. For example, the OBO community has supported efforts into making quality ontologies easier to develop and maintain via concentration on practices and tools supporting open collaborative workflows, often

centered on GitHub, including editing, quality control releases and infrastructure. Taken together, the community effort involving professional data and knowledge curators, as well as ontologists help make OBO ontologies more trustworthy and actively supported and responsive to new requirements.

With some ontology edits it is difficult, if not impossible, to model consistently since humans are not good at repetitive tasks. As an aid tools from the OBO community support repetitive tasks are discussed in the subsections below.

ROBOT

ROBOT is one of the tools in the OBO development stack (Jackson et al., 2019). It is a well documented, command-line tool and library for automating OWL ontology development tasks. Based on shared best practices, it uses Java code (e.g., interface command to extract or merge ontologies or core operations such as comparing ontologies) to automate repetitive tasks needed to create and manage OWL-based ontologies such as controlling ROBOT from Python. ROBOT can also be used to:

- Convert an OWL ontology to various formats
- Extract a module from an ontology
- Merge an import to an ontology or unmerge by removing axioms from an ontology
- Mirror by making a local copy of an an import chain
- Report ontology measures and
- Provide control on ROBOT operations via Python scripts.

A ROBOT template can be used to create an ontology or selected parts of an ontology.

The Ontology Development Kit

Constructing an ontology involves developing and implementing the ontology in a computer-readable format. This may involve using an ontology editor such as Protégé or a programming language to create the ontology. Higher-level tools to simplify the process but also provide a richer ontology. The ODK, which has been developed and maintained by the

Open Biological and Biomedical Ontologies (OBO) Foundry, uses a Docker containerization platform to hold a toolbox that can be used to develop and maintain ontologies. Docker makes ODK easy to install and use, as well as being scalable and secure.

The released version of an ontology can take several forms, depending, for example, on whether there has been reasoning over the ontology or whether it contains imported axioms from external ontologies. To facilitate interoperability and modular reuse of ontologies, the ODK defines a few standardized release products, such as the "base" product, which contains only native axioms, and the "full" product, which also includes imported axioms and axioms inferred by logical reasoning (Matentzoglu et al., 2022).

The ODK tools can be used to:

Create new ontologies The ODK provides a set of tools that can be used to create new ontologies from scratch as well as to edit them.

Publish ontologies The ODK provides a set of tools that can be used to publish ontologies to the web.

Test ontologies The ODK provides command-line tools that can be used to test ontologies such as checking for errors and ensuring that the ontology is consistent.

Document ontologies ODK provides command-line tools that can be used to generate documentation for ontologies such as generating HTML documentation and OWL documentation. Note: ontology design pattern approaches also recognize similar documentation requirements for a quality ontology (pattern). These include documenting the pattern with a Schema Diagram, examples of Pattern Instantiation, a list of competency questions, axiomatization documentation, a link to an OWL File, Pointers to Related Patterns, and pattern Metadata.

Ontology Access Kit

The Ontology Access Kit (OAK) is a set of Python libraries and tools supporting access to ontologies. Some ways in which OAK can be used include:

Loading ontologies OAK provides a simple way to load ontologies in various formats, such as OWL, RDF, and OBO. Once an ontology is loaded, it can be queried and manipulated using the OAK API.

Querying ontologies OAK allows people to query ontologies via the OAK API, which provides an easy way to express complex queries over an ontology to find all classes that have a particular property, all individuals that belong to a certain class, or more complex reasoning tasks.

For all these reasons OAK can support evaluation and testing to ensure that an ontology meets the requirements and specifications of the stakeholders and that the ontology is consistent. This may involve testing the ontology against a set of use cases or scenarios.

Dashboards

Once in use, an ontology needs to be maintained and updated to ensure it remains relevant, accurate and useful. Maintaining an ontology involves adding new content (e.g., classes) or revising existing content to reflect changes that occur in the domain of interest. For example a project may want to update and change the way they model a concept like "river" so that in a drought a river need not contain water, but still acts as a container for water. When adding new terms, a merging phase that aligns resources typically takes place. If a modular approach is used, merging is followed by a reengineering phase of the new terms into modules.

The conceptualization of a given concept or class may also change over time. In the context of an open-source project, such as OBO, ontology change starts with submitted change requests via an online platforms (such as GitHub), followed by planning of changes, implementing the change and evaluating the effect to decide if a proposed change should be implemented. With large ontologies, as in the OBO Foundry, the management of a consistent ontology across version updates and their dynamics is a major challenge and requires tool support. If the ontology can be localized to one cultural language, a formal implementation phase to represent the conceptualization in an ontology language is next followed by a Maintenance Phase for improvements and corrections.

The OBO Dashboard has been developed and maintained by the

Open Biological and Biomedical Ontologies (OBO) Foundry. The OBO Foundry provides a set of principles guiding ontology development, offers help in reviewing new ontologies, and aids existing ontologies to improve their community alignment, metadata standards, and provenance annotations (Jackson et al., 2021). The work of the OBO Foundry is also assisted by a tool called the Ontology Quality Assessment Toolkit which automatically assesses all references (e.g., IRIs or CURIEs) in the ontology, including in semantic mappings, provenance, properties, and other metadata for consistency (OQUAT, n.d.). OQUAT produces web-based reports that community members can review and use as the basis for improvements. Typical consistency issues detected by OQUAT include typos within prefixes (e.g., Wikidata instead of wikipedia), non-standard usage of identifiers which violate the expected pattern, or unknown prefixes that aren't already registered in the Bioregistry (Hoyt et al., 2022; Bioregistry, n.d.).

Assessment features included in a Dashboard to gauge the quality of an ontology, include:

Metadata OBO Dashboards provide a summary of the metadata for an ontology, such as the name, version, and license.

Statistics OBO Dashboards provide statistics about the size and structure of an ontology, such as the number of classes, properties, and individuals and feedback to users on updates.

Conformance since interpretation of principles is not always easy, OBO Dashboards provide operationalized definitions so that responses can be used to assess whether an ontology conforms to the OBO Foundry principles, a set of guidelines for developing high-quality ontologies.

ROBOT Report OBO Dashboards can be used to generate a ROBOT Report, which is a comprehensive report that assesses the quality of an ontology against a set of criteria.

Knowledge Graphs

Knowledge graphs are applications that help to organize and structure data and information in a way that is easy to understand and navigate.

Because they have some formal structure that is intuitive to people they can be helpful to humans and processable by machines.

As discussed in Baclawski et al. (2021) ontologies are a semantic resource along with RDF encoded data. They are useful in building KGs by helping to structure knowledge graphs populated with RDF triples and by providing a common consistent vocabulary and set of relationships for describing the data. If done effectively it makes it easier to understand the KGs data, to reason about it, and to integrate it with other knowledge graphs.

However, there is an associated task and challenging task of mapping data in the KG to the appropriate concepts and relationships defined in the ontology. Keeping a good mapping as the KG evolves can be challenging. The experience of the OBO Foundry community's work and the development of Ubergraph is illustrative.

Ubergraph is a recursive RDF hypergraph data structure providing a public SPARQL endpoint to 50+ OBO ontologies loaded and pre-reasoned with simple triples. Ubergraph is used in the NCATS Biomedical Data Translator Program to create a unified view of biomedical data, such as genetic and clinical trial data as part of tracking research results that can improve the discovery and translation of new biomedical knowledge. As opposed to an axiom based representation found in the OBO Foundry ontologies, it is a general-purpose graph data structure for simplified querying supporting directed and undirected edges, weighted edges, node and edge attributes, and a mixture of directed and undirected edges within a single graph.

A knowledge graph outside the BioMedical area of note is the NSF-funded KnowWhereGraph (KWG) which is a densely populated cross-domain knowledge graph that incorporates over 30+ thematic and "placial" datasets into a KG using over 13.5 billion triples. Although some large ontology design patterns like Sensor, Observation, Sample, and Actuator (SOSA) are used along with space and time ontologies, unlike Ubergraph, it's starting point is not a family of related domain ontologies, but data sets that are formalized as concepts - object, data, and annotation properties. The schema strategy is to isolate instantiated patterns into modules, and then interconnect them into a coherent graph.Together, they provide a

wealth of highly diverse sources (hazard events, places, and people) of relevant spatial and non-spatial information about the location of features (like rivers), the relationships between features, and the properties of features to form an open, extensible, standards-based, and spatially-explicit knowledge graph. Together with a geo-enrichment service stack for applications in the environmental domain, the KWG schema integrates different kinds of data and their relationships. Users may not have to have special knowledge such as a special language of space and time to access information about topics such as:

- Environmental monitoring: The KWG can be used to monitor the environment for changes, such as changes in land use, changes in water quality, and changes in the distribution of species.
- Natural disaster response: The KWG can be used to support the response to natural disasters, such as floods, earthquakes, and wildfires.
- Sustainability planning: The KWG can be used to support the planning of sustainable development projects, such as the development of renewable energy projects and the protection of natural habitats (Janowicz et al., 2022).

The knowledge engineering for KWG uses the "pattern-mediated methods" discussed in the Modular Ontology Modeling section above combined with metadata scaffolding to quickly assemble background knowledge, improved alignment and an overall schema to improve reusability. OpaL, (Object, Process, Actor modeling Language) is an ODP representation language that can be used for assembling modules. It is designed to support domain experts who need to build an ontology by providing a limited number of high level conceptual templates (D'Antonio et al., 2007).

Remaining Challenges

Despite much progress, many challenges remain to helping scientific researchers develop and make better use of ontologies. Templates, patterns, and tools can support the ontology engineering process. However, communities such as Biomedicine and GeoSciences have somewhat different histories and tackle different problems. As a result, best practices are not yet employed for some domains, with research teams in these areas having a learning curve to realize best practices.

It remains to be seen, for example, if we can reuse templates from different domains such as biomedicine, industry, finance and geoscience. In OBO a particular, specialized group may set up its specific template for use and similar things may have to be done in other domains. In all domains there are some best practices that only experienced ontologies are likely to handle such as how to reify a time sensitive relation or apply the idea of a role relation.

To some degree the US effort on ontologies has been concentrated in the biomedical realm while in the EU the effort seems more concentrated on training a new generation on techniques that may then be applied more widely (Hitzler, 2022). The OBO community is engaged with large ontologies while domains outside of this may be looking at schemas with a modest number (thousands) of entities and in some cases employing lightweight axioms. Another issue is the scope of a templated design pattern. Reusable components need to be large enough to not be obvious, yet small enough to not be overwhelming and difficult to understand. Currently OBO templates are relatively small, while something like SOSA is much larger but still manageable. It is reasonable to expect that more domains will soon be faced with scaling problems, just as the OBO community has.

Current ontology engineering methods are too low-level. Regardless of the size of an ontology, we need higher-level approaches as part of the simplification. Currently basic semantic web tools (OWL-API and reasoners that are part of Protégé) were used to create the large KWG. However, reasoners may be overrated for some tasks; the Shapes Constraint Language (SHACL), a W3C recommendation for describing and validating RDF graphs, may be more effective than OWL. SHACL can be used to constrain elements of a KG by specifying that all instances of a particular class must have a certain property, or that the values of a particular property must be drawn from a specific list.

For ontology editing mid-level languages such as Turtle or the Manchester syntax, make the textual inspection and editing of ontologies easier, but graphical visualization remains an important enabler in many practical tasks related to ontologies especially as ontologies have grown in size and complexity. The Protégé editing tool includes a basic visualization capability (Protégé visualization, 2023) and plugins, such as OntoGraph

or OWLViz. Ontology libraries such as BioPortal also provide visualization as do the plugins that are part of the NeOn Toolkit. Tools such as VOWL allows some degree of useful structural inspection, but not visual editing or readily showing the structural consequences of changes. Standalone tools can be downloaded and installed on an end-user system, while web-based visualization tools enable the user to upload or select the ontology they want to visualize. Some examples of other ontology visualization tools are OWLGrEd, NavigOWL, Knooks, and TGViz (Joseph and Lourdusamy, 2020). Some tools allow a particular graphical representation such as UML-based diagrams into OWL. Despite the ability of plugins to allow new functionality there remains a need for some general ontology visualization framework that guides how to move from a conceptual model to ontology coding (Dudáš et al., 2018). Such a framework would include a core set of visual and interactive features that would be harmonized with templates. As with the system of OTTR templates that would allow extension and customization from a base to serve a family of related use cases. Better conceptual visualization of knowledge is also needed to aid in reaching domain agreements and arriving at working knowledge.

A large challenge is to establish and maintain harmonization across a range of semantic resources. Definitions are an essential part of ontologies, but early in an ontology's development they are often poorly written, incomplete or rigid and thus hard to formalize in a useful way. Some ontology efforts find reuse difficult and start anew using their own ideas. In many domains the practice of reusing extant ontologies for particular applications remains difficult, since the scope of the original ontologies competency questions may not have good overlap with a new application. Under these circumstances it is often easier to build new ontologies. Addressing this problem remains an issue since the result is various knowledge silos across the semantic spectrum that include definitional silos in glossaries which involve alternative conceptualizations. As a result, ontologies may suffer because of a lack of experience with writing definitions or simply because there is a lack of emphasis on properly defining terms during the ontology development process. Semantic resources for definitions sources, such as glossaries, can help but may vary widely on the same topic and are often inconsistent with one another. The challenge of agreeing on common conceptualizations across a domain and the wide range of semantic

resources that must be harmonized has been extensively been discussed in the Ontology Summit 2021 Communiqué (Baclawski et al., 2022).

Vocabulary alignment is challenging because:

- Arduous review is necessary due to the need to consider every term.
- Granularity of terms frequently differ (broader, narrower, ambiguous)
- Definitions/descriptions usually differ. For example, terms may be related but reconciling differences can be challenging.
- Formal axioms are often different.

For all these reasons, harmonization of concepts is important throughout the ontology lifecycle as an ontology is updated and made interoperable with other ontologies (Baclawski et al., 2022). And there remains a challenge to develop better tools for harmonization.

Discussion of Tool Issues

There are many and varied tools at different levels of maturity to consider, making it difficult to know how to judge their value. Only a few evaluations of ontology tools have been conducted (Duineveld et al., 2000; Malik, 2017). These efforts are somewhat dated and do not systematically cover the full range of evaluation from:

- Functionality across the lifecycle,
- Performance such as execution time,
- Usability such as interface robustness,
- Ease of learning,
- Intuitiveness, overall user experience
- Interoperability such as integration with other software tools commonly used in the ontology engineering process, and
- Community adoption.

However, in the BioMedical realm there are some tool overviews. These include Python tools (Semantic Python Overview, n.d.). a curated list of ontology resources including tools (Awesome Ontology, n.d.), and a

range of tools across different development packages (Awesome Semantic Web, n.d.).

Within the engineering lifecycle adequate tool development and maintenance is still needed over time. This reflects in part a prototype problem as argued by Vigo, Matentzoglu, Jay and Stevens (2019). Too many ontology authoring tools remain prototypes that are not widely used by groups beyond a narrow domain scope. Tool maturation requires funding such as was the case for Protégé tooling.

There is also an issue with how well integrated tools might be to an engineering methodology such as modular development.

ML/AI Techniques

Machine learning techniques have advanced rapidly and knowledge sources from text extraction, such as vector space embeddings, are now often used in developing KGs to represent the same type of artifacts as ontologies: entities, relationships, and attributes. Such embeddings capture semantic relationships and similarities between entities, enabling various graph-related tasks independently of what is formalized in ontologies. The emerging use of Knowledge Graph Embeddings as input features of machine learning methods has given even more visibility to this kind of representation, but raises new issues of understandability and interpretability of such embeddings. These include what the embeddings represent, understanding the logical connections between the graph and its embeddings and how they relate to the structure and semantics of what people understand and have formalized in the semantic resources that may underlie the KG.

An active area of research focuses on how to integrate traditional symbolic representations,as found in ontologies, with machine learning approaches. There is a rich possibility of unifying these 2 approaches (symbolic and connectionist) , symbolic and connectionist approaches, with different representations as well as reasoning. There are ongoing efforts to study the compatibility between ontological knowledge and different types of vector space embeddings (Kulmanov et al., 2020).

Ontology Maturity

Maturity of Ontology has been proposed by several authors (Obrst, 2009; Doerr, 2014). While Obrst refers to linkages with databases as level

3 and axiomatized, inference, persistent management of domain semantics at level 5, Doerr refers to A. Scope, B. Domain based answers to research questions with constant terms, C. Classes as carriers of properties.

Open extensible ontologies need to be measured by not only semantic richness but also other measures such as usability by domain experts (scientists and practitioners), related domains-overlap and cross-domain relevance (may be indices!), and reuse by applications.

While the Zachman framework has been extensively used by Industry, Federal and State Entities including Defense for describing the knowledge of an enterprise, it can also be described as akin to an irreducible description capturing the state of Enterprise (Zachman framework, n.d.; Sharma, 2000). The use of the Zachman framework includes many areas of applications, standards, tools, technologies, vocabularies and objectives, and success related to maturity is in actual implementation of enterprise. While very mature data captures about the enterprise are kept in masterdata and metadata, this interpretation of the Zachman framework implies maturity of the enterprise in terms of extent of knowledge and progress in terms of AS-IS and TO-BE gap analysis, and how to reach the target state. We are attempting a similar gap analysis notion in this communiqué for ontology tools and their domain use and developing notions of maturity as we do for software engineering.

Ontologies may also be used for Enterprises such as Finance (e.g., the Financial Industry Business Ontology) and Manufacturing (e.g., the Zachman framework). An example of maturity in the Zachman framework is measured by the levels reached across rows and columns and most matured Enterprises include implemented models including items such as BPM, Standards adherence and Reuse through replication of tools, standards and infrastructure. The maturity in the development phases of ontologies can be compared to Capability Maturity Model Integration (CMMI) maturity levels (CMMI, n.d.). The final test of ontology-maturity is perhaps related to Logic, Reasoning, Inference and Cognitive power and visualization through tools such as Knowledge Graphs, Formal Notations such as BPMN, other metamodels, etc. There are other methods such as Gartner Hype Cycles and Forreser studies that represent the maturity and life cycles of tools, technologies and standards, eventually predicting

the operational and sunset phases. We expect these tools to have different peaking and operational phases and eventual replacement by better solutions!.

Summary and Conclusion

We have shown how one can mitigate the difficulties that typical end-user researchers encounter when developing and employing ontologies. These include techniques for initiating the development of an ontology, examples of tools tools that can be used, and how to maintain an ontology after its development. Higher-level work on ontologies can begin by securing cross community cooperation, agreements and common tool use. The ontology reuse, templates and design patterns are important techniques. While significant progress has been made, these it is still challenging to make effective use of these techniques Addressing this challenge requires a broad, yet in-depth, analysis of ontologies, ontology design patterns, and their potential to provide a usable, common basis that others can effectively use.

Templated abstractions can be used with formalisms such as RDF and OWL. Doing so allows non-ontologists to use, capture, and instantiate standard abstracted patterns for activities such as type checking. Standardized formats need to be adapted for domain experts, data managers and ontology experts. The templates and ODPs can be published in template libraries using LOD principles and related tools that must be open source and well managed. However, it remains challenging to design patterns that are general enough to be able to cover a wide variety of applications and uses. Of course, it is necessary to bear in mind that there can be cultural, operational, ideological and political differences among the communities that employ ontologies, as well as varying domain challenges. Consequently, continued work on the adaptation of templates for new ontology development will be needed.

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References

Alani, Harith, et al. (2002). "Managing reference: Ensuring referential integrity of ontologies for the semantic web." Knowledge Engineering and Knowledge Management: Ontologies and the Semantic Web: 13th International Conference, EKAW 2002 Sigüenza, Spain, October 1–4, 2002 Proceedings 13. Springer Berlin Heidelberg.

Awesome Ontology download site (n.d.). https://bit.ly/3G6xqYt

Awesome Semantic Web download site: Python (n.d.) https://bit.ly/3slndE2

Baclawski, Ken, et al. (2021) "Ontology Summit 2020 Communiqué: Knowledge Graphs." *Applied Ontology* 16(2): 229–247. https://bit.ly/34fFVOi

Baclawski, Ken, Michael Bennett, Gary Berg-Cross, Leia Dickerson, Todd Schneider, Selja Seppälä, Ravi Sharma, Ram D. Sriram, and Andrea Westerinen (2022). "Ontology Summit 2021 Communiqué: Ontology Generation and Harmonization." *Applied Ontology* 17(2): 233–248. https://bit.ly/3mhNlIP

Bennett, Mike, and Baclawski, K. (2017). "The role of ontologies in linked data, big data and semantic web applications." *Applied Ontology* 12(3-4): 189–194.

Berg-Cross, G., Duerr, R. et al. (2023). "Semantics Adoption in the Earth and Environmental Sciences: Successes and Roadblocks" https://bit.ly/3G0trg1

Bioportal website (n.d.). https://bit.ly/3u4edUx

Bioregistry website (n.d.). https://bioregistry.io

CMMI (n.d.). https://cmmiinstitute.com/

Carriero, V. A., Gangemi, A., Nuzzolese, A. G., and Presutti, V. (2019). An Ontology Design Pattern for representing Recurrent Events. In Proceedings of the 10th Workshop on Ontology Design and Patterns (WOP 2019) co-located with the 18th International Semantic Web Conference (ISWC 2019), Auckland, New Zealand, K. Janowicz, AA Krisnadhi, MP Villalón, K. Hammar and C. Shimizu, eds, CEUR Workshop Proceedings, volume 2459. https://bit.ly/45Zkm1j

D'Antonio, Fulvio, Michele Missikoff, and Francesco Taglino (2007). "Formalizing the OPAL eBusiness ontology design patterns with OWL." Enterprise Interoperabil-

ity II: New Challenges and Approaches. Springer London.

Doerr, M. (2014). Answer to "Is there a maturity model for ontologies?" Research Gate. https://bit.ly/40tDeUU

DOSOP, 2023. https://bit.ly/49hwWMa

Dudáš, Marek, et al. (2018). "Ontology visualization methods and tools: a survey of the state of the art." *The Knowledge Engineering Review* 33: e10.

Duineveld, Arthur J., et al. (2000). "WonderTools? A comparative study of ontological engineering tools." *International Journal of Human-Computer Studies* 52(6): 1111-1133.

FAIR Principles (n.d.). https://www.go-fair.org/fair-principles/

Fürber, Christian, and Christian Fürber. (2016). Semantic technologies. Springer Fachmedien Wiesbaden.

Grüninger, Michael, Uschold, Michael and Guarino, Nicola, Application Framework Synthesis (2011), in Uschold, Michael. "Making the case for ontology." *Applied Ontology* 6(4): 377-385.

Hahmann, Torsten, Shirly Stephen, and Boyan Brodaric (2016). "Semantically refining the groundwater markup language (GWML2) with the help of a reference ontology." International Conference on GIScience Short Paper Proceedings. 1(1).

Hahmann, Torsten (2023). Upper Level Domain Models, Briefing at the Ontology Summit 2023. http://bit.ly/3KgnvCg

Hitzler, Pascal (2022). Panel on FAIR semantic resources, organized by Gary Berg-Cross and Asiyah Lin, 4th U.S. Semantic Technologies Symposium, October, 2022.

Hitzler, Pascal, and Cogan Shimizu (2018). "Modular ontologies as a bridge between human conceptualization and data." Graph-Based Representation and Reasoning: 23rd International Conference on Conceptual Structures, ICCS 2018, Edinburgh, UK, June 20-22, 2018, Proceedings 23. Springer International Publishing.

Hoyt, C.T., Balk, M., Callahan, T.J. et al (2022). Unifying the identification of biomedical entities with the Bioregistry. *Sci Data* 9: 714. https://bit.ly/3sc1QFm

Hoyt, C.T., Hoyt, A.L. and Gyori, B.M. (2023). "Prediction and curation of missing biomedical identifier mappings with Biomappings." *Bioinformatics* 39.4: btad130.

Jackson, Rebecca C., et al. (2019). "ROBOT: a tool for automating ontology workflows." *BMC bioinformatics* 20: 1-10.

Jackson, R., Matentzoglu, N., Overton, J. A., Vita, R., Balhoff, J. P., Buttigieg, P. L., ... and Peters, B. (2021). OBO Foundry in 2021: operationalizing open data principles to evaluate ontologies. *Database*. https://bit.ly/47075XK

Janowicz, Krzysztof, et al. (2022). "Know, Know Where, KnowWhereGraph: A densely connected, cross-domain knowledge graph and geo-enrichment service stack for applications in environmental intelligence." *AI Magazine* 43(1): 30-39.

Joseph, M. F., and Lourdusamy, R. (2020). Feature analysis of ontology visualization methods and tools. *Computer Science and Information Technologies*, 1(2), 61-77.

Katifori, Akrivi, et al. (2007). "Ontology visualization methods—a survey." *ACM Computing Surveys* (CSUR) 39(4): 10-es.

Krieg-Brückner, Bernd, Till Mossakowski, and Mihai Codescu (2021). "Generic Ontology Design Patterns: Roles and Change Over Time." WOP (Book).

Kulmanov, Maxat, et al. (2020). "Machine learning with biomedical ontologies." biorxiv: 2020-05.

Linked Open Vocabularies (n.d.). https://bit.ly/3Qoijy9

LinkML website (n.d.). https://linkml.io

Malik, Zeeshan Haider (2017). "Usability evaluation of ontology engineering tools." 2017 Computing Conference. IEEE.

Matentzoglu, Nicolas, et al. (2022). "Ontology Development Kit: a toolkit for building, maintaining and standardizing biomedical ontologies." *Database*: baac087.

Musen, Mark A., et al. (2018). "CEDAR: semantic web technology to support open science." Companion Proceedings of the The Web Conference 2018.

Neuhaus, F. and Smith, B. (2010). Ontology Summit 2010 Communiqué: Creating the Ontologists of the Future. http://bit.ly/2fOGuIO

Neuhaus, F. et al. (2011) Creating the ontologists of the future, *Applied Ontology* 6(1) 91–98. https://bit.ly/3FOU3R2

Noy, Natalya, et al. (2010). "The ontology life cycle: Integrated tools for editing, publishing, peer review, and evolution of ontologies." AMIA Annual Symposium Proceedings. Vol. 2010. American Medical Informatics Association.

OBO (2023). Open Biological and Biomedical Ontology Foundry, Community development of interoperable ontologies for the biological sciences. http://obofoundry.org/

Obrst, L. (2009) The Ontology Maturity Model. https://bit.ly/3CUAqDs

Obrst, L. and Musen, M. (2008) Ontology Summit 2008 Communiqué: Towards an Open Ontology Repository. http://bit.ly/2fOGs3E

OQUAT (n.d.), Ontology Quality Assessment Toolkit. https://bit.ly/471g2QD

Otte, J. Neil, John Beverley, and Alan Ruttenberg (2022). "BFO: Basic formal ontology." *Applied Ontology* 17(1): 17-43.

Protégé visualization (2023). Visualization - Protégé Wiki (stanford.edu)

Rudnicki, R., Smith, B., Malyuta, T., and Mandrick, C. W. (2016). Best Practices of Ontology Development, October 25, 2016. CUBRC: Buffalo, NY, USA.

Semantic Python Overview download site (n.d.). https://bit.ly/40tCX4k

Shimizu, Cogan, and Karl Hammar (2019). "Comodide–the comprehensive modular ontology engineering IDE." ISWC 2019 Satellite Tracks (Posters and Demonstrations, Industry, and Outrageous Ideas) co-located with 18th International Semantic Web Conference (ISWC 2019) Auckland, New Zealand, October 26-30, 2019.. Vol. 2456. CEUR-WS.

Shimizu,C., Hitzler, P and Krisnadhi, A. (2020). "Modular ontology modeling: A tutorial." In Cota, G., Applications and Practices in Ontology Design, Extraction, and Reasoning, *Studies on the Semantic Web.* Volume. 49.

Shimizu, Cogan, Karl Hammar, and Pascal Hitzler (2023). "Modular ontology modeling." *Semantic Web*, 14(3): 459-489.

Shimizu , Cogan (2023). Introduction to Patterns and Modules, Ontology Summit 2023.

Skjæveland, Martin G., et al. (2018). "Practical ontology pattern instantiation, discovery, and maintenance with reasonable ontology templates." The Semantic Web–ISWC 2018: 17th International Semantic Web Conference, Monterey, CA, USA, October 8–12, 2018, Proceedings, Part I 17. Springer International Publishing.

Skjæveland, Martin G. (2023). "Reasonable Ontology Templates (OTTR)," Ontology Summit 2023 presentation, April 19, 2023. https://bit.ly/3KHDmbW

Sorbonne Declaration (2020). Sorbonne Declaration on Research Data Rights. https://sorbonnedatadeclaration.eu/

Suárez-Figueroa, Mari Carmen, Asunción Gómez-Pérez, and Mariano Fernandez-Lopez (2015). "The NeOn Methodology framework: A scenario-based methodology for ontology development." *Applied Ontology* 10(2): 107-145.

Zachman framework (n.d.). The Zachman framework. Wikipedia. https://bit.ly/4756zI6

Appendix 1: NeOn glossary of terms

Ontology network A set of ontologies that are related to each other and that are used to represent a domain of interest

Ontology A formal, explicit specification of a shared conceptualization

Ontology engineering The process of creating, maintaining, and using ontologies

Reuse The use of existing ontologies or parts of ontologies to create new ontologies

Reengineering The process of adapting existing ontologies to meet new requirements

Collaboration The working together of people to achieve a common goal

Distributed environment An environment in which people are working together on a project but are not located in the same place

Scenario A description of a typical use case for an ontology network

Appendix 2: Phases of work and NeOn Scenarios

In NeOn seven phases of work are used, as shown in Figure 3, starting with an Initiation Phase that creates a requirements Specification and project Scheduling. As in true of all phase evaluation of the scheduled work, early phase follows a rational project path and defines the problem by:

1. Identifying the criteria used to judge possible solutions (e.g., functional requirements and/or competency questions for ontologies or alignment with a certain vocabulary to provide interoperability)
2. Deciding how important each criterion is (e.g., Must this ontology use the Common Ontology for BioMedicine as a starter set? Or "For efficiency should I use a ROBOT template?")
3. Generating a list of possible alternatives
4. Evaluating the possible alternatives before making a selection.

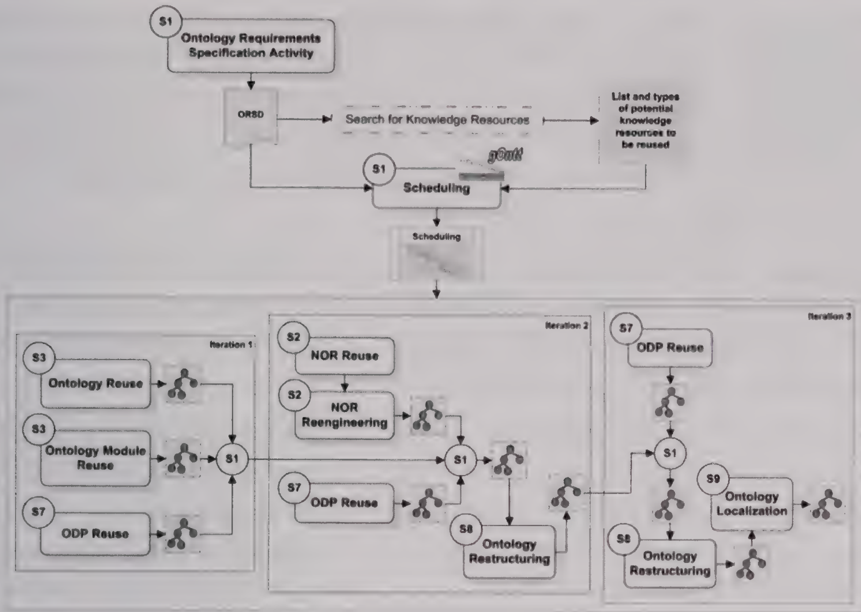

Figure 3: Graphical depiction of several different steps in ontology development, where each step has its methods and interactions with other steps (Suárez-Figueroa et al., 2015)

Appendix 3: The Reasonable Ontology Templates and Methodology

The OTTR templates are accessible through a template library hosted at https://tpl.ottr.xyz/, following linked data principles. These templates offer a more intuitive and abstract approach to ontology definition by employing a range of related templates for conceptualizing entities. In addition to compositional patterns akin to those used in OBO, OTTR provides templates for triples and class typing, serving as alternatives to the direct composition of complex OWL code. Furthermore, OTTR templates address OWL language-specific challenges such as handling blank nodes and default values.

Each OTTR template begins with a unique identifier and a descriptive name, facilitating top-down modeling that starts with a high-level, conceptual perspective of the ontology's structure. This initial step involves

identifying and defining the pivotal concepts and relationships to be captured within the ontology. Since not all concepts are initially known, as the process evolves, templates can be utilized iteratively. Domain experts can contribute to a spreadsheet containing their proposed concepts, which is subsequently expanded to encompass relationships, properties, and other pertinent elements.

By leveraging OTTR templates, ontology developers can streamline their modeling workflow, enhance collaboration with domain experts, and progressively refine their ontologies by iterating through concept expansion and relationship establishment.

Following base development users arrive at the more demanding task of class restrictions. These are progressively refining and expanding it through creation of high-level OTTR templates that capture the structure and constraints of the ontology components. Templates in OTTR also support parameterization, which allows users to define patterns with placeholders that capture different aspects of ontology elements and provide flexibility in generating OWL code for repetitive ideas. Templates that can be populated with specifics although there may be issues such as global fields which are often inadequate for common items. For example one gets name collisions for ambiguous,common words such as "member" or "time" that might be used in populating a template. Domain terms such as "equipment" need specific restrictions like "equipment can only have equipment as a part."

OTTR templating also enables a clear separation of ontological representation concerns by distinguishing template definitions that capture the structure and constraints of ontology components, from the template instantiations which allows users to populate the templates with relevant information, such as class names, property values, and individual instances. This separation simplifies the process of modifying or extending ontologies without directly modifying the base code.

Following initial instantiation, users can iteratively refine the ontology by expanding and modifying the templates based on the evolving requirements and domain understanding. This refinement process involves adding more specific details, defining additional relationships, and incorporating domain-specific constraints.Users can instantiate templates again with updated data to generate expanded code. This repeated instantiation and ex-

pansion process allows users to incorporate the changes and improvements made during the iterative refinement step. Finally to ensure the correctness and integrity of the ontology validation and testing is supported by testing the evolving ontology code against domain constraints, consistency rules, and desired ontological principles.

Importantly OTTR templates are designed to handle the underlying semantics of OWL, which means they can enforce certain constraints or rules during code generation. This semantic-awareness helps in maintaining the integrity and consistency of the resulting OWL ontologies. The code generation process built around OTTR templates resolves parameters and applies the provided data to the templates, to produce a final, usable OWL representation.

Templates can also serve as a simple checklist to ensure that important, core aspects of the ontology have been considered during design.

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JAMES A. OVERTON is an open source software and ontology developer, specializing in data integration for open science databases. As a member of the OBO Technical Working group he builds and maintains tools and infrastructure for an open community of more than 200 scientific ontology projects. As president of Knocean Inc. he and his team have helped scientific databases at NIEHS, NIAID, EBI, universities, and other institutions use ontologies to integrate, validate, analyze, and share FAIR data.

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